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SPATIAL LEARNING IN VIRTUAL ENVIRONMENTS BY CHILDREN AND ADULTS AFTER ACTIVE OR PASSIVE EXPERIENCE

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Abstract

Theories of spatial learning, such as those of Siegal and White (1975) and Piaget and Inhelder (1967) have considered active exploration of environments to be beneficial or essential for the development of specific spatial knowledge. Real world empirical research in the form of both laboratory experimental and broader environmental studies tends to support this suggestion, demonstrating that active exploration of an environment, in both children and adults, gives better spatial learning than passive experience. Based on these findings, the working hypothesis adopted in this thesis is that active exploration of a virtual environment (VE) would also result in better spatial learning than passive experience of the same VE. Also considered is the equivalence of real and virtual world experiences, and the degree of transfer of spatial learning between VEs and real equivalent environments. Seven experiments were undertaken, all utilising a yoked active-passive paired-subjects design. A range of VEs was employed across the experiments, including a room, a corridor, and both complex and simple small towns. Three studies used children as participants and five, adults, all having both males and females. The key finding was that the experimental hypothesis was supported for children but not for adults. Active child participants (when using a familiar input device) demonstrated superior spatial learning to that of their passive counterparts, but active adult participants did not show superior spatial learning to that of passive counterparts. Underestimation of distances was a universal feature, but was greater in female than male participants. Otherwise, the general equivalence of real and virtual world experiences was confirmed, with transfer of spatial learning occurring from virtual environments to real world equivalent environments for both adults and children.

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Publications stemming from this research prior to final binding of the thesis

Sandamas, G. and Foreman, N. (2007). Spatial reconstruction following virtual exploration in children aged 5-9 years: Effects of age, gender and activity-passivity. Journal of Environmental Psychology. Doi: 101016/j.jenvp.2007.03.001

Sandamas, G. and Foreman, N. (2007). Drawing maps and remembering landmarks after driving in a virtual small town environment. Journal of Maps, v2007, pp 35-45.

Foreman, N. Sandamas, G. and Newson, D. (2004). Distance in virtual space is sensitive to gender but not activity – passivity. Cyberpsychology and Behavior, 7 (4), pp 451-457.

Sandamas, G. and Foreman, N. (2003). Active and passive spatial learning from a desk-top virtual environment in male and female participants: A comparison with guessing controls. Journal of Health, Social and Environmental Issues. 4 (2), pp 15-21.

Foreman, N. and Sandamas, G. (2002). Human spatial cognition: Current issues and technological developments. Khabarshi Vestnik; Al-Farabi University Journal. 1 (8), pp 38-48.

All of the above publications are presented in Appendix 2

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Chapter 1

INTRODUCTION

Spatial learning in virtual environments by children and adults after active or passive experience

The following introductory chapter is presented for the purpose of setting the context of the current thesis, providing definitions of key terms and informing the reader of the structure and subsequent content of the thesis. It is not intended as an in-depth literature review as each study reported within the body of the text has its own introduction, and these serve as literature reviews in themselves.

Space and spatial cognition

According to Cohen (1985) spatial cognition as the specific focus of philosophical interest can be traced back as far as the rationalism-empiricism debate of Plato and Aristotle in the 4th Century BC. Siegel and White (1975) have also pointed out that the ability of humans to understand the arrangements of objects in space has been the subject of inquiry by philosophers and neurologists long before it came to the attention of psychologists. Since the current thesis is concerned with space and human knowledge about spaces it is appropriate that at the outset, a brief discussion concerning the nature of space and spatial cognition is undertaken.

Philosophically speaking, the concept of space is controversial and those who have attempted to define it have fallen, by and large, into two camps:

proponents of absolute space or relative space. Philosophers such as Plato and Clarke, who advocate an absolute conceptualisation, proposed that space is independent of the objects contained within it and that even when the objects are removed the framework provided by absolute space remains constant. Therefore, implicit within an absolute concept of space is the idea that the observer's perception and viewpoint are irrelevant to the conception of it (Liben 1981).

Alternatively, the idea of relative space places far more emphasis on the role of objects within space and the observer's perspective. For Leibnitz and Kant, space is altered as a function of the differing spatial relations between the objects within it and the view an observer has of it. That is, a change of object position relative to other objects alters the nature of space, as does a change of the observer's perspective, and therefore the idea of empty space has no meaning; space is *defined by* its content and how it is viewed.

From the standpoint of a psychologist, the phenomenological concept of relative space would appear to be more appropriate in terms of understanding human cognitions about the spaces they know. Whilst it may be implicit in the influential work of Piaget and Inhelder (1967), on the development of spatial abilities, that the concept of absolute Euclidean three-dimensional space is the most mature view and the last to be acquired ontogenetically (Liben 1981), of more relevance to the current thesis is the concept of relative space. In terms of the current investigations the construct of relative space has greater utility, as it emphasises the roles of both object and observer and comprises within its definition the concept of place. Liben (1981) proposes that the concept of "place" is concerned with the environment and knowledge concerning specific locations, whilst the concept of space is more concerned with spatial abstractions and concepts in general. The current thesis is not intended as a philosophical evaluation of the nature of space but as a practical investigation of human spatial learning related specifically to acquired environmental spatial knowledge and alternative ways in which that knowledge may be acquired.

In practical research terms the differentiation between place and space does not necessarily require a different methodological approach but rather a different interpretation of what the data indicate. For instance, children asked to construct a model of their classroom or sketch a map of their route to school are demonstrating both their specific knowledge of their environment (knowledge of place) and their abilities in terms of spatial concepts such as topological relationships, reference systems and distances (knowledge about space). Both types of knowledge come under the rubric of spatial cognition and both are influential in the formation of spatial mental representations. However, data interpretation depends on the concerns of the investigator. As indicated above the perspective of the current investigation is more concerned with the formation of place knowledge (what might be called Environmental Cognition) than abstractions concerning space, although it is acknowledged that any investigation concerning spatial representations will inevitably tap both knowledge bases.

As humans, generally speaking, we take for granted our spatial knowledge concerning the environments with which we are familiar, also that we can learn about novel spaces given time and experience within them. Kevin Lynch (1960) proposed that a significant motivation for humans to mentally represent environments in some spatially organised way is the fear of being lost. The personal anecdote below demonstrates the importance of knowing where you are, where you are going, and, if necessary, how to get back!

"The motorbike was parked in an underground car park no more that five minutes walk from the hotel. As my wife packed I left to collect it. An hour later I was still riding around Barcelona trying to find my way back to the hotel. I was lost and my lack of Spanish did not help! After riding around for a while, however, I began to recognise places we had visited during our stay and by a process of guesswork and directional intuition managed to find my way back to where I had started, hotter and not a little more stressed than when I had left."

According to Kaplan (1976), as humans move through an environment, they acquire knowledge about the spatial relationships of objects and places encountered within it and this information takes the form of a mental representation or 'cognitive spatial map'. A key role in the development of cognitive maps is familiarity (Acredolo, 1982), and places repeatedly experienced close together in time – for instance when walking through a building – become associated within a mental representation (Kaplan and Kaplan, 1982). Or, as Siegel and White (1975) put it, " Spatial knowledge arises from the integration of successive perceptual experiences" (p. 20).

Children attending new schools become familiar with the various routes between school and home – refining them over time - in addition to learning the layout of school corridors, classrooms, dining areas and playgrounds and the spatial relationships between them. For children in particular, autonomous spatial environmental experience allowing spatial choice facilitates the ontogenetic development of spatial cognition and associated brain structures; indeed, differences in spatial perception have been found between children accompanied to school and those travelling alone (Joshi, MacLean and Carter, 1999). At the microgenetic (developing spatial knowledge of a specific environment) level, children able to make their own way to school and home again are able to explore and deviate from regular routes, thus widening their spatial experience and developing way-finding strategies such as correcting routes, making detours, and finding short-cuts (Foreman and Sandamas, 2002).

For adults, the same principles apply. A new job may initially require that a warm bed be left unnecessarily early because the only known route to work is not the most direct or efficient. However, as familiarity with the new journey increases, more direct and or faster routes are discovered. Also at a new place of work the layout of the office or factory may initially be confusing, though with time and experience this novel environment will also become familiar allowing the new employee to make informed directional and route choices.

A substantial body of literature investigating the effects of familiarity on spatial / environmental cognition set in diverse environments ranging from the very large [neighbourhoods and cities (Beck and Wood, 1976; Appleyard, 1970; Lynch, 1960)] to the medium [offices, hospitals and schools (Moeser, 1988; Garling Lindberg and Mantyla, 1983; Acredolo, Pick and Olson 1975)] and to the small [class rooms (Herman and Siegel, 1978)] have all found evidence to suggest that the accuracy and utility of cognitive maps increase with environmental familiarity.

All of the above scenarios and many others that involve environment-person interactions require that the actors learn about the spatial composition of the environments in which the activity is taking place. That is to say, in order for humans to successfully navigate the environments they inhabit they need to mentally store information concerning the spatial arrangements of those environments. Possessing such mental "maps" will have been instrumental in ensuring escape from danger and the acquisition of live food in all of our early ancestors. It has been suggested that this information is held in the form of a mental or cognitive spatial map. Siegel and White (1975) proposed that the development of these spatial representations follow a particular course both ontogenetically, by children mastering spatial relations (a view held in common with Piaget and Inhelder, 1957) and microgenetically, by adults learning new environments. Landmarks as route-orienting objects are encoded first and may mark decision points such as junctions; then the routes between landmarks are encoded in the form of sensori-motor routines. Finally, as knowledge of both routes and landmarks becomes more detailed and enriched it also undergoes a process of integration so that a survey type mental representation or map of the environment is developed. A person who has developed such a representation of an environment has the knowledge to navigate never-previously-experienced routes between landmarks if the need should arise.

There is some disagreement concerning the validity of the cognitive map hypothesis, since Olton (1978) argued for spatial representations as lists of scenarios (the 'list hypothesis), an idea that received subsequent support from Brown (1992). Nevertheless, the cognitive spatial mapping concept, in one form or another, is the most generally and widely accepted model within the wider psychological community. The process proposed by Siegel and White (1975) for the development of cognitive maps has also been subsequently challenged and an alternative process proposed by Montello (1998), these two alternative views are considered in the materials to follow. In addition, egocentric/kinesthetic strategies such as path integration or "dead reckoning" (Gallistel, 1990) can be used to compute location, by up-dating one's position according to a vectorial system in which the turning and forward movements made from a point of origin can be stored. This is particularly necessary when landmarks are not perceptually available (see Garling, Selart & Book, 1997). Thus a path can be reversed, and from any location a participant can point back to the origin. The primary function of such spatial representations, be they in the form of cognitive maps as proposed by Siegel and White (1975), a series of local views as proposed by Olton (1978), a situation-dependent combination of the two (Brown, Rish, VonCulin and Edberg, 1993) or vectorial computations, is to prevent humans and other animals from getting lost and to facilitate movement and location within large scale environments. Thurstone (1938) suggested that spatial cognition can be regarded as a separate component of human intelligence, and Cohen (1985), following a review of the literature, suggested that thought concerning spatial qualities is somehow different from other types of thinking.

John Hughlings Jackson (1876) provided early neurological evidence of the separateness of spatial thinking and other abilities. He found that, in addition to other spatial deficits, a woman who suffered damage to the right hemisphere of her brain was no longer able to navigate a journey with which she was previously highly familiar. Similarly, Forster (1890; cited in Stiles-Davis, Kritchevsky and Bellugi, 1988) described a patient whose language, visual recognition and other cognitive functions appeared intact, but who was unable to comprehend the spatial layout of environments. Tolman (1948) coined the phrase *cognitive map* in his seminal work 'Cognitive maps in rats and men', in which he claimed that rats generate cognitive maps of the spatial layouts of their environments and use these for practical navigation. O'Keefe and Dostrovsky (1971) further developed Tolman's work and provided a physiological model of spatial navigation when they discovered place cells with location-specific activity in the rat hippocampus. Later O'Keefe and Nadel (1978) argued that while "taxon" (egocentric) and "locale" (allocentric) systems are available for navigation, spatial information about the layout of a learned environment is maintained within the hippocampus in the form of a cognitive spatial map.

More recently brain scanning studies have provided strong evidence that spatial cognition in humans is associated with activity in hippocampal and para-hippocampal brain structures (Maguire, Frith, Burgess, Donnett and O'Keefe, 1998) and the cortical areas projecting to the para-hipocampus (Aguirre, Detre, Alsop and D'Esposito, 1996). Maguire, Frackowiak and Frith (1997) found, using the brain scanning technique positron emission tomography (PET), that when they asked licensed London taxi drivers to recall complex routes around London the right hippocampus and associated brain regions became highly activated. They concluded that the hippocampus is involved in the processing of spatial layouts established over long periods of time. A later study (Maguire, Gadian, Johnsrude, Good, Ashburner, Frackowiak and Frith, 2000) compared the hippocampal volume of experienced London cabbies with controls. They found that the cabbies had significantly larger posterior hippocampal regions and that the extent of enlargement correlated with the number of years spent driving taxis.

Developmentally speaking, spatial cognition has also been regarded as involving separate and special skills, although the child's understanding of space is thought to develop in parallel with other cognitive abilities through the successive stages of development (Piaget and Inhelder, 1967). The pre-operational child understands topological relationships such as 'next to' or 'in front of' but the egocentric nature of his thinking interferes with his ability to represent another's visual perspective. The concrete operational child, however, recognises the effect of changes of viewpoint and can imagine another's perspective; that is to say, the concrete operational child begins to understand the projective properties of space. Finally, the formal operational individual comes to understand the metric properties of Euclidean space such as depth. As children get older, this also has implications for the storage of relevant knowledge; older individuals have greater spatial experience and therefore a better developed knowledge base concerning both specific and abstract space

(Liben, 1981). Many studies have shown that the spatial learning of children benefits greatly from direct autonomous experience with the environment, an issue that will be elaborated throughout this thesis.

How do we best learn about the layout of an environment?

As mentioned above, familiarity with an environment leads to an understanding of that environment's spatial properties and the formation of a mental representation that can be thought of as a cognitive map. However, the ways in which a person becomes familiar with a novel environment may be more or less effective for spatial learning. For instance, does autonomous active exploration of an environment lead to better spatial learning than more passive experience? Or to put it another way, does the person who walks, cycles or drives around a novel environment (making directional choices combined with the physical effort to action those choices) have an advantage over the person who experiences the same environment as a passenger, the latter having no control over their spatial decisions and displacements?

The idea that active locomotor experiences within environments lead to greater and more flexible spatial knowledge than physically passive experiences stems from a number of theoretical perspectives including those of Piaget (see above) and it has become generally accepted (see Siegel and White, 1975 for a review). Cohen and Cohen (1985) suggest that "Actively moving through the environment brings the individual into contact with the multiple perspectives of the space and facilitates the integration of views and the co-ordination of percepts with motor experiences" (p. 213). For children this may be more advantageous than it is for adults since autonomous spatial experience within environments requires spatial choices to be made, which in turn enhance the development of spatial cognition and associated brain systems and structures (Foreman and Gell, 1990; Foreman and Sandamas, 2002).

Empirical evidence from both experimental and environmental studies has also tended to support the premise that active exploration of large-scale environments - those that demand *participation* rather than just passive observation (Ittelson, 1973) - facilitates spatial learning. The concept of scale is important here and is, according to Cohen (1985), distinct from size. Large-scale spaces are defined by Siegel and White (1975) as those that surround the individual and are comprehended through the co-ordination of multiple perspectives. In the literature, large-scale spaces can range from room size to city size and greater. Interestingly, much of the prominent evidence supporting the idea that adult spatial learning benefits from activity comes from urban/naturalistic (city size) studies, the main purpose of which was not to investigate this phenomenon per se. Conversely however, much of the evidence supporting the idea that spatial learning in children is facilitated by activity comes from studies conducted in experimental laboratory (room size) environments. Both the theoretical perspectives and the empirical evidence for the benefits of activity are reviewed in the introductory sections of the reported studies that form the subsequent chapters of this thesis.

Thus, for large-scale environments, activity, both from an empirical and theoretical perspective, is generally considered as being beneficial for spatial learning. However, of primary interest for the current investigation is whether or not this also applies to spatial learning within virtual environments (VEs); i.e., does activity benefit active explorers of virtual large-scale spaces as it does those of real large-scale spaces? Does it elevate their spatial knowledge acquisition above the levels achieved by individuals who have only passive (observational) experience of virtual exploration?

Virtual environments (VEs) are created using virtual reality (VR) software. (The term VE will be used generally in preference to VR, which carries an unrealistic assumption that the participant is transported into an alternative reality; VR will be used where it is historically appropriate). Virtual Environment technology is based on relatively new computer software that is an offshoot of Robotics and Teleoperation technologies. One definition of VR is that it represents an advanced human-computer interface that is able to depict realistic 3-dimensional environments with which participants can interact in pseudo-real time (Ellis, 1994). The three dimensional simulations are generally presented either via a standard desktop monitor or via a head-mounted display (HMD). The latter comprises two small screens held in front of the viewer's eyes and displaying separate L and R eye views, on a head-mount to offer what is arguably (Slater & Usoh, 1995) a more authentic three-dimensional visual experience. The current investigations utilise desktop or screen projection VEs only, since these are affordable, user friendly, and have been shown in previous studies to afford good spatial learning following virtual exploratory experiences (cf. Foreman et al, 2003; 2005). Movements within VEs are effected via the use of input devices such as a keyboard (using the arrow keys), mouse or joysticks. Chapter 1 gives a brief description of the history and technical details of VR displays.

Many studies have shown that the exploration of VEs is realistic and authentic, insofar as participants who are allowed free exploration of a simulation can afterwards make accurate and sophisticated judgements about the relative positions of encountered landmarks, and make optimal shortest route judgements between specified targets (see Wilson, Foreman and Stanton, 1998, for a review) suggesting that they form cognitive maps of the virtual environment. Thus, despite the abnormality of desktop VEs, including sensory limitations such as narrow visual field extent (when compared to normal human vision) movement within a virtual large-scale space such as a building reproduces, to a large extent, the experience of moving within the equivalent real building. In addition, a number of studies have shown that spatial information acquired from virtual exploration transfers accurately to real equivalent environments and although virtual exploration has been shown to lead to marginally less accurate spatial performance on some measures (Wilson, Foreman and Tlauka 1997), skills acquired from virtual exploration are adequate for most practical spatial tasks. Reviews of relevant studies that have utilised VEs to investigate spatial learning are provided within the introductory sections of the reported studies below.

Therefore, to summarise, the current thesis explores the benefits of active exploration of VEs for spatial learning, compared with more passive experiences of virtual environments. It comprises a series of experiments that have utilised a range of methods and participant samples but that have all been based on two main premises, one, that in the real world spatial learning is facilitated by activity (Piaget and Inhelder 1967; Appleyard 1970; Siegel and White 1975; Feldman and Acredolo 1979; Herman 1980; Hart and Berzok 1982) and two, that spatial learning in VEs is equivalent to spatial learning in the real world (Stanton, Wilson and

Foreman 1996; Wilson, Foreman and Tlauka 1996; Ruddle, Payne and Jones 1997; McComas, Pivik and Laflamme 1998; Peruch & Gaunet 1998).

Following a logical progression from these two premises it was hypothesised that activity in VEs should be advantageous for spatial learning in the same way as it has been reported as being advantageous in real space.

Outlines of the following chapters

Chapter 2 asks, "What is virtual reality?" It provides the reader with a brief history and description of a range of virtual reality systems and some of the uses to which they have been put beyond the sphere of spatial cognition research. It is not intended as an exhaustive review of VR systems and technology (for that see Stanney, 2002) but as an informative background piece providing contextual information with which to consider the main body of research.

In **Chapter 3** [Experiment 1], "Transfer of spatial learning from Virtual to Real Space in Children", the effects of differential modes of exploration, age and familiarity", a partial replication is described of the real world study conducted by Herman (1980), who found that children who explored a model town by actively moving through it learned more about its spatial layout than children who viewed it from the perimeter. Forty-six females and 40 males aged 6-9 years twice experienced a virtual model moving through it in 'yoked' active / passive pairs or viewing individually from the perimeter. After each virtual encounter the children reconstructed the virtual model using a to-scale real model. Replicating Herman's findings, significant main effects for Age and Trial were revealed, indicating that accuracy of reconstruction improved as a function of age and familiarity. However, contrary to the experimental hypothesis, passive participants' scores improved to a greater extent than did those of active participants. A number of possible explanations for this unexpected finding are suggested including issues related to working memory and use of the input device: the mental effort required to use the input device, but also the lack of physical effort required.

In **Chapter 4**, "The effect on children's spatial learning of prior training in the use of an input device used to actively explore virtual environments", it was hypothesised, based on the findings of Experiment 1, that participants inexperienced with the use of even simple computer input devices might experience interference between the concurrent tasks of (a) using an input device to navigate within a VE and (b) learning the spatial layout of the VE. This study used the same procedures and models as those used in the previous study except that the participants - 26 females and 16 males aged 7-8 years – were given prior training in the use of the input device. The findings replicated those of the previous study except that on this occasion, active participants' scores improved to a significantly greater degree than did those of passive participants, as predicted by the experimental hypothesis. It was proposed that this finding indicates that training may reduce cognitive loading, enabling active explorers of VEs to benefit over passives in the same way as do active explorers of real environments.

In **Chapter 5**, "Does increasing motor demand whilst simultaneously reducing cognitive effort lead to more accurate distance estimations in VEs?" A study is reported, also based on the findings of Experiment 1, in which it was hypothesised that input devices requiring greater physical effort and more naturalistic movements to initiate and maintain virtual-movement might enhance spatial learning in terms of estimating the distances between objects. Four groups of undergraduates each divided equally across males and females experienced a movement along a corridor containing 3 distinctive objects, in a VE with wide-screen projection. One group simulated walking along the virtual corridor using a proprietary step-exercise device. A second group moved along the corridor in conventional flying mode, depressing keyboard keys to initiate continuous forward "flying" motion. Two further groups observed the walking and flying participants, by viewing their progress on a monitor screen. All participants then had to walk along a real equivalent but empty corridor, and indicate the positions of the 3 objects. All groups underestimated distances in the real corridor, the greatest under-estimations occurring for the middle distance object. Males' under-estimations were significantly lower than females' at all distances. However, there was no difference between the active participants and passive observers in either walking or flying conditions.

Chapter 6 asks, "To what extent do concurrent tasks affect spatial learning of simple virtual environments?" The study presented in chapter 3 demonstrated that training in the use of a simple input device was associated with improved spatial learning for active participants, and this finding was interpreted in terms of training reducing the load on working memory. An alternative method of investigating the effect of working memory load on spatial learning is to have participants perform concurrent tasks. Five groups of participants, with 8 females and 4 males in each passively observed virtual exploration of a small room environment in which there were 6 floor-standing objects. Controls did nothing while observing, but experimental groups performed secondary tasks that made different spatial working memory demands: a verbal memory task (remembering a list of concrete nouns: no spatial demand), a simple spatial motor task (simple card-turning: low demand), or a complex spatial-motor task (either sequential spatial card-turning, or key board key depression shadowing observed screen displacements: both high demand). Participants subsequently had to locate 5 of the objects on a map of the room, one object remaining as a reference point. Only complex card-turning and keyboard shadowing significantly impaired object location memory compared with controls. Since these tasks most closely approximate the spatial working memory demands made by input devices used to control virtual displacements, device control may reduce the benefits of activity for spatial information-gathering in virtual environments by competing for working memory capacity.

In **Chapter 7**, "Active and passive spatial learning from a desktop VE in male and female participants: a comparison with guessing controls", the question is asked. If there is no difference between the spatial representations of active and passive participants, is this because they are equally *good* at remembering the spatial layout of a VE or equally *bad*? The study compares the spatial memory performance of participants (32 males and 32 females) who had either actively explored or passively viewed a VE with each other and with naïve (guessing) controls. Theory, and previous research findings, suggests that participants should attain significant spatial learning from a VE though this has hitherto not been formally tested in the context of an active / passive comparison. Undergraduate participants therefore explored a desktop virtual rendition of a room containing 6 floor placed objects. Active explorers used the keyboard keys to control displacements whilst their passive counterparts observed. The active–passive pairings were of the same sex. Following exploration, participants were asked to indicate the positions of 5 of the 6 objects on an A4 paper floor plan of the VE. The 6th object was represented on the floor plan as a reference point. The guessing controls performed the same task but without having experienced the VE. There was no difference in placement accuracy between active and passive conditions but both were significantly more accurate than the guessing controls. These results concur with those of several previous studies that have found no differences between actives and passives on subsequent tests of virtual spatial knowledge acquisition, but contrasts with real world studies where differences have been found. In addition to this, they also confirm that spatial information transfers well from virtual to real space and that this applies equally well to those who have had either a passive or active virtual experience.

Chapter 8 investigates "The effects of active versus passive exploration and familiarity on the acquisition of spatial representations of a virtual urban space". In an attempt to recreate the driver-passenger active-passive scenario (Appleyard, 1970; Hart and Berzok, 1986) often quoted by researchers in the area as indicating the benefits of activity, 54 undergraduate participants (45 females and 9 males) moved through a, complex virtual-reality small town in 'yoked' active–passive pairs. In the active (driver) condition, the participant used a proprietary steering wheel and pedal (accelerator/brake) arrangement to navigate through the VE, as if driving, while in the passive (passenger) condition the participant sat next to the active participant. Active participants were instructed to follow road-markings leading them and their passengers through all of the town's streets ensuring that each pairing experienced equivalent exposure to the environment. Passive participants were instructed only to attend to the screen. Participant pairs were also sub-divided into three exposure conditions to investigate the effects of familiarity on the development of spatial representations. It was hypothesised that active participants would learn more about the environment than passives and that this difference would increase as a function of length of exposure. However, whilst no active–passive differences were found, significant differences for length of exposure were demonstrated on several measures of spatial knowledge of the VE. The findings support previous research indicating the benefits of familiarity for spatial learning but do not support Siegel and White's (1975) proposal for the sequence in which spatial knowledge of an environment manifests. It was hypothesised that the lack of active–passive difference may have been due to the fact that active (driver) participants had to follow road markings and did not, therefore, make autonomous directional choices and thus that exploration did not have a specified purpose.

The study presented in **Chapter 9**, "Self directed and task specific exploration of virtual environments does not enhance spatial learning", follows on from the study presented in chapter 7 and attempted to address the methodological problems that were identified as possibly leading to an absence of differences in spatial learning being found between active and passive participants. In this study, active participants explored freely; that is to say did not have to follow any directions and exploration was goal-oriented as opposed to being aimless. It was hypothesised that these alterations to the methodology should enable active participants to demonstrate greater spatial learning than their passive counterparts. Thirty-four undergraduate participants (27 females and 7 males) explored the to-be-learned VE in yoked active–passive pairs for 10 minutes looking for a number of specified locations. Again, active–passive differences in spatial learning were not apparent although a significant advantage was indicated on some of the measures of spatial learning for experienced real-world car drivers. Also, as in the previous study (chapter 7), correlations between the measures of spatial learning were more supportive of a parallel model of spatial knowledge acquisition rather than a serial one as suggested by Siegel and White (1975).

Chapter 10 provides a discussion of all of the foregoing studies.

Research Ethics

The research reported within the body of this thesis was conducted in accordance with the guidelines laid down by The British Psychological Society of which the author is a member. Ethical approval was sought from and granted by Middlesex University's Psychology Ethics Committee, who work within these guidelines, for all of the experiments reported below. All experiments not conducted on Middlesex University property were subject to a risk assessment prior to data collection. All participants were fully debriefed and given the right to withdraw themselves and / or their data at any time and fully informed consent was obtained. These studies involved only mild deception in that experimental hypotheses per se were not revealed to participants prior to participation. Consent was sought from the parents of all participants under the age of 16.

Chapter 2

What is "Virtual Reality"? History, Systems and Applications

Due in part to the historical antecedence of this relatively new technology and also to its relative novelty, definitions vary of what "Virtual Reality" (now, more commonly, virtual environment [VE] technology) consists of, and factions within the 'VR community' do not always agree on what it encompasses. Kalawsky (1994) has suggested that there are as many definitions as there are people working in the field. Moreover, definitions must evolve to embrace the seemingly perpetual development of ever more powerful computers running ever more sophisticated software and interface devices.

Carande (1993) described VR in the broadest terms, and rather optimistically, as, "*A computer-generated reality.*" (p. ix). He acknowledged that this definition is inadequate but argued that it covered a myriad of possibilities whilst circumventing much of the dispute as to what constitutes VR. Eddings (1994) suggested that VR can be defined simply as the simulation of alternative worlds generated by computers utilising specialised hardware and software, while a more prosaic and complete definition of VR is suggested by Nugent (1991) who proposed that VR is:

"A computer-synthesised, three-dimensional environment in which a plurality of human participants, appropriately interfaced, may engage and manipulate simulated physical elements in the environment and, in some forms, may engage and interact with representations of other humans, past, present or fictional, or with invented creatures." (In Larijani [1994], p. 9)

Nugent's definition, which extends other definitions by encompassing the multi-user interactivity aspect, arguably contains all the essential features of VE systems -- computer generation, three-dimensionality, and environments with which humans can interact in pseudo-real time, in which almost anything is possible. Also, although VEs are usually presented visually, and often exclusively visually, it is important to note that VR systems can also simulate inputs to other human sensory modalities (usually auditory and tactile).

Nevertheless, the definitions of VR given above all neglect to include one aspect which divides the VR community: some believe that for any system to be termed "VR" it must be 'fully immersive', isolating the user from the real world within a head-mounted display (HMD) that provides a stereoscopic image. On the other hand, many regard non-immersive systems, utilising fast 3-D graphics, and standard computer monitors or other flat screen displays, as being perfectly adequate to provide effective VE experience (Wilson, 1997).

The following sections will briefly describe immersive and non-immersive systems, their advantages and disadvantages, and the uses to which they have been put.

Immersive Systems

It was the development of the Head Mounted Display (HMD) by Ivan Sutherland during the 1960s that created public interest in VE systems and also created the strong association between VR and sensory immersion. HMDs contain two miniature screens (either cathode-ray-tubes or, more recently liquid crystal arrays), displaying left eye and right eye views of a computer- generated three-dimensional scene. Under these conditions, left and right eye images become fused in the brain into a single image having depth and extension. In other systems, a miniature optical array magnifies, collimates and projects the images directly into the wearer's eyes, via a mirror combiner, creating the perception of the original image at optical infinity (Barfield and Furness, 1995).

An alternative way of achieving such effects is via the use of shutter glasses (Eddings, 1994), which can also produce stereoscopic effects that give flat 3-D images the property of extent -- that is, the image appears to have true depth. Shutter glasses work by alternately making the left and right hand lens opaque and transparent (while one is opaque the other is transparent) using liquid crystal technology (Vince, 1998). This process is synchronised by signals from the host computer and happens at speeds that are fast enough that a participant is unaware of the switching. Close and Open times of 2ms and 2.8ms respectively are typical (information courtesy of Stereographics plc). This rapid cycling results in left and right eye images being conveyed to the two eyes separately and apparently simultaneously, and, as with an HMD the two images fuse in the brain to create a single 3-D stereoscopic image.

In addition to providing stereoscopic depth, an HMD also incorporates a motion-tracker to monitor the wearer's head movements and relay information about them to the host computer, which updates the image correspondingly. Sutherland wrote, *"The fundamental idea behind the three-dimensional display* *is to present the user with a perspective image which changes as he moves"* (Sutherland, 1968, p. 757).

HMDs also immerse the user in a virtual world by preventing them from seeing the real world. This exclusivity is believed by some to be a requirement for any system proclaiming itself as VR since it is said to increase the sensation of presence within the virtual world (Vince, 1998), so that while an immersive VE is experienced, the user no longer pays attention to the computer display. The user is literally made to feel immersed in the virtual world and his or her movements in real space are translated, by various interfaces, into equivalent movements in virtual space.

Ideally, immersive VR interface equipment facilitates intuitive user movement and to this end, in addition to head-trackers, data-gloves can be utilised, which relay information concerning the user's hand movements to the computer. Within the virtual world the user can see, for instance, a virtual hand, the movements of which correspond with the movements of his or her own hand in the data glove. Using their virtual hands, users can manipulate virtual three-dimensional objects and also operate virtual three-dimensional devices such as switches, levers and buttons. Standard data gloves have positional data transmitters capable of sending data to the computer system only, though more sophisticated data gloves can receive system outputs as well. This feedback can take the form of such tactile sensations as pressure, heat and texture, and can serve to augment the user's virtual experience. Body suits work on the same principle as data gloves and relay positional information concerning all of a user's body movements to the computer. The more sophisticated body suits have the facility to convey tactile sensations to the wearer. It has been suggested that input and feedback body suits would be particularly suitable for use in such diverse areas as biomechanics, sports medicine, movement assessment and rehabilitation, sex therapy and erotica (Larijani, 1994).

Alternative immersive systems to the HMD have been developed and include the BOOM (Binocular Omni-Orientation Monitor) and the CAVE (Cave Automatic Virtual Environment). The BOOM is similar to the HMD except that it is mounted on a counterbalanced arm, the position of which can be tracked by a computer. The user, either standing or sitting, holds the BOOM, using side-grips, snugly to their face and looks into it in the same way as a submarine captain looks through a periscope. Some of the advantages of BOOMs are that they can be used for longer periods of time than HMDs, since they do not have to be worn by the user, and for the same reason, they can utilise heavier displays with greater resolution than is practical for use with HMDs (Larijani, 1994). In addition, as the BOOM is self-supporting it requires little in the way of adjustment when shared between different users, unlike an HMD, which is worn.

The CAVE display, first developed at the University of Illinois in 1992, uses rear projection to create what is in effect a room containing a virtual world, capable of simultaneously immersing up to 10 people at one time, only one of whom acts as a 'guide', controlling the virtual experience with either a HMD-position tracker, 3-D mouse, or a 'wand' (a hand-held device containing a position sensor and control buttons). To perceive the three-dimensional display those within the CAVE must wear stereoscopic shutter glasses. The degree of immersion is very high although only the guide interacts directly with the environment whilst others in the group can observe in order to share in the experience.

Vehicle simulators fall somewhere between fully immersive and non-immersive systems because although the user is not wearing an HMD and is fully aware of the real space around him, s/he is, in fact, engaged with and immersed in a virtual scenario. Also known as Cab systems, vehicle simulators comprise the physical facsimile of a vehicle interior in which the user sits. The windows of the vehicle are computer screens on which are displayed a virtual outside world. This virtual world is slaved to the vehicle controls in much the same way as it would be to a head-tracking device in an HMD. However, in this instance it is not head movements that cause a perspective change in the virtual environment but movement of the vehicle controls. Flight and driving simulators fall into this category.

Flight simulators have long been used for the training of military and commercial pilots and have been a major driving force behind the development of VR systems. Flight simulators offer a safer and cheaper training alternative than using real aircraft, added to which they offer pilots the opportunity to practice a greater number of take-off and landing scenarios than would otherwise be practicably possible. In addition, flight simulators also allow pilots to experience the effects of diverse weather conditions and rarely encountered (or survived) scenarios such as aircraft near misses, wind shear, engine failure and or other mechanical breakdowns (Eddings, 1994). Today, pilots can practice take-off and landing procedures utilising simulations of every major international airport in weather conditions ranging from fog to rain to snow to electrical storms. The airport simulations also provide animated features of hazards such as moving traffic on motorways adjacent to runways, moving ground support vehicles and other aircraft landing and taking off (Vince, 1998). Pilots sit in a cockpit designed to precisely mimic the flight deck of a real aircraft in terms of controls, dimensions and so forth. In many instances these are bespoke items built to provide pilot training for specific aircraft. Computer screens serve as the cockpit windows on which the virtual scenario is presented, slaved to the flight deck controls and to all intents and purposes the pilot is totally immersed in a virtual world. The enclosed cockpit is mounted on a platform supported on a number of hydraulic rams that are also slaved to the flight controls and serve to alter the orientation of the cockpit. Within the flight simulator pilots are unable to see the outside world and do not have access to any external cues that can help them understand their orientation. Because of this, when the front of the flight deck is raised by the hydraulic rams, causing the pilots to be pushed back into their seats, they experience the sensation of acceleration. Conversely, when the rear of the flight deck is raised, causing them to lean forward in their seats, they experience the sensation of deceleration. The hydraulic rams alter the orientation of the cockpit cabin in response to the flight controls and the degree of lift equates to the degree of acceleration or deceleration felt by the pilots.

In addition to training pilots, the military also use VE technology for a number of other applications. Realistic virtual simulations of military environments have been created for a range of tasks including weapons training, parachuting, war gaming, bomb disposal, operations planning, aircraft carrier landings, fire fighting, submarine piloting, and others (Stone 2002). A specific example of one of the uses to which the military has put VE technology is that of the Avionics Training Facility at the Tornado Maintenance School at RAF Marham in Norfolk. Utilising a sophisticated desktop VR system to train maintenance crews, instructors have found that the time taken to successfully complete the course has been reduced to 9 weeks. Prior to the introduction of the VE training programme, in 1999, training was conducted using real scale models of the Tornados and took 13 weeks (Stone, 2002). The United States military, a major developer of VE technology, has developed a system for networking simulations into the same environment (Eddings, 1994). The Close Combat Tactical Trainer (CCTT), as it is known, can link vehicle simulators and personnel, immersing all participants and objects into the same simulated battle scenario regardless of where they may be in reality. Soldiers based in Europe can play war games with those based in the United States, for instance. Utilising the CCTT network global simulations of helicopters, fighter-planes, tanks and all kinds of military vehicle can simultaneously interact within the same virtual reality environment.

Non-Immersive Systems (Desktop VEs)

The term "non-immersive VR" is synonymous with the presentation of virtual environments on desk top monitors, usually using personal computers fitted with appropriate graphics cards to create and present VE simulations. The computer monitor provides a window through which participants may view the virtual world (Eddings, 1994). Coming into prominence during the late 1980s and early 1990s (Carande, 1993), desktop VR coincided with the development of affordable home and work computers powerful enough to generate interactive three-dimensional images. Up to this point VR had been mainly the domain of the military, gaming, and industry- and government-sponsored research institutes, able to afford the prohibitive costs of the hardware needed to support immersive VR environments. Even to date, true consumer-grade HMDs do not exist. Many researchers express their disappointment at the performance offered by the inexpensive specialist immersive hardware to which their research budgets restrict them (Blade and Padgett, 2002).

Typically a desktop VE system offers a monitor-based two-dimensional image using conventional laws of geometric perspective and depth cueing (the use of shading, texture mapping, interposition and other visual prompts to give the user cues to the distance of an object), giving the impression of a three-dimensional world. However, users do not experience full immersion because, firstly, the computer hardware is still obvious to them and second, they are not isolated from the real world. However, despite these limitations, utilising specialist three-dimensional software it is possible to create navigable virtual environments, with which users can interact in pseudo-real time. For instance, an architect could create a virtual model of a planned development and run it on a desktop system allowing prospective clients to view the virtual building from every conceivable angle, added to which, alternative design options can be explored before actually commencing the building construction. The approach of British Nuclear Fuels Ltd (BNFL) perfectly illustrates the efficacy of desktop VR as not only a design tool but also a medium for training. Before BNFL built a new control room for one power station they had their design modelled in a VE using Superscape's VRT software. This not only allowed for an evaluation of seating plans, the positioning of critical equipment, and other ergonomic factors, but also the training of operators prior to the room being built and used (Vince, 1998), presumably saving time, reducing cost and minimising the risks of costly design and operating errors.

As discussed above, movement within an immersive VE is usually mediated by 3-D motion trackers built into HMDs, data gloves, and data suits. These devices translate the user's natural physical movements into corresponding displacements within the virtual world. However, whilst data gloves may be used in conjunction with desktop systems to manipulate virtual objects, for instance, devices such as 3-D mice, joysticks and steering wheel and pedal arrangements (as in a conventional vehicle) are used to navigate around desktop VEs. As with immersive systems, these devices allow the user to explore with up to 6 degrees of freedom of movement; 3 spatial dimensions (height, width and depth) and three degrees of orientation (rotation, yaw and pitch). Alternatively, many software packages allow for the use of a 2-D mouse (a standard computer 2-button mouse) in conjunction with on-screen buttons, which can be 'clicked on', also to give 6 degrees of freedom of movement. This approach is based on the WIMP (Windows, Icons, Mouse and Pointer) paradigm (Bryson, 1995) in which the user is presented with a view of a 3-D scene in which a 'window' is embedded, usually along the bottom edge of the screen, containing a collection of control items. Using a standard 2-D mouse the user manipulates the control icons to change the 3-D view presented on the computer monitor.

Presence and Immersion

In general terms presence may be described as the sense (or illusion) of being located in a certain place at a certain time. In terms of the presence provided in a VE, this can be described as a cognitive state, in which the user has an illusory sense of actually being present in the virtual world that is presented on the computer display. In other words, *"Presence is the impression of being within the virtual environment."* (Bricken and Coco, 1995, p.108). Slater and Usoh (1995) suggested that, ideally, a high degree of presence within a virtual environment should lead users to experience the virtual world as temporarily more real than the real world setting, such as the laboratory in which they are experiencing the VE. Such a sense of presence is likely to lead to the user into briefly forgetting the real world outside of the VE and interacting with the virtual world in a similar fashion as they would if it were real. This may not be an instant effect; many researchers report that the process of forgetting and ignoring the real world occurs progressively as the user becomes engaged with activities in the VE.

A key factor in the level of presence felt by users of VEs is arguably the degree of immersion offered by any particular system (Slater and Usoh, 1995). An immersive system that provided visual, auditory, tactile and olfactory stimulation allied to a display driven by the natural movements of a user's body, offering proprioceptive feedback, would offer an extremely high degree of immersion. Add a wider field of view and greater display resolution and the degree of immersion increases again. However, any decrease in the number or sophistication of the interface devices and the level of perceived immersion decreases accordingly. As suggested by Slater and Usoh (1995), the degree of immersion is at least a partial ordering. However, since people's responses to VEs are, to a certain extent, governed by their dominant sensory modality (Slater and Usoh, 1994) the degree of presence experienced by an individual is unlikely to be a straightforward linear function of the level of immersion. Nevertheless, the ideal VE system offers a high degree of presence, such that if they want to take a closer look at an object, they can just move towards it; if they want to pick it up they just reach out and grasp it, and do so with spontaneity. Bricken and Coco (1995) suggested that the ease with which the attention of a VE user can be drawn away from the interface devices and into an inclusive VE experience is the real measure of presence. They go on to suggest that, *"By creating a closed loop between physical behaviour and virtual effect, the concepts of digital input and output are essentially eliminated from perception."* (p. 110). According to Slater and Usoh (1995), *"The aim of modern virtual reality systems is to consummate this tightly coupled loop."* (p. 59).

However, against this positive view of immersion and presence is the fact that where people experience disorientation in VEs, this is especially associated with the use of head-immersion devices (Darken and Silbert, 1997). In addition, not everyone can adapt to the use of immersion helmets since they can give rise to cybersickness, especially in older participants (Liu, Watson and Miyazaki, 1999).

To date, immersive VE systems have yet to deliver on the promise of a virtual experience into which the user may easily step and feel fully included. Due to the limitations of displays, tactile and kinaesthetic interfaces, and a host of other technical restrictions, we are still a very long way from the 'Holo-Deck' scenario portrayed in the television program 'Star Trek: The Next Generation'. The Holo-Deck is a fully immersive VR device (a 24th century CAVE) in which the crew of the star ship Enterprise can spend their recreation time individually or in groups. Within the Holo-Deck they can explore holographic simulations of solar systems, planets, cities and buildings, real or imaginary whilst interacting with historical or fantasy figures in scenarios of their own devising. The VR worlds created within the Holo-Deck are perceptually and experientially indistinguishable from reality and do not require the user to wear any input/output devices such as HMDs, gloves or body suits.

Up to this point, presence has been discussed in the context of immersive VR, though due to cost, accessibility and technological limitations, the majority of VE systems currently being used around the world are based on the desktop paradigm. Obviously these so-called 'low-end' systems cannot offer the same degree of immersion as 'high-end' systems, even when used with shutter glasses. However, they can nevertheless offer the user an impressive degree of presence within a virtual environment. As with fully immersive systems, desktop VR allows the user to interact with an environment in pseudo-real time utilising a range of external interface devices, including 3-D mice and data gloves. The facility to navigate around virtual space and manipulate virtual objects utilising external devices means that, in essence, the user is virtually present within the screen-based world by, as Carande (1993) puts it, "*... having motion outside the screen isomorphically represented as an agency within it.*" (p. xiv). Eddings (1994) argued that, although not fully immersive, desktop VR games offer a high degree of interactivity. The game player enters into the game via the spatial link afforded by the computer monitor to the depicted scene and plays from a first person perspective. Players can navigate around the worlds in which the games are set with the ability to rotate through 360 degrees. They may also make decisions on game scenarios, by choosing between alternative 'portals'. This in turn affects a myriad of possible game outcomes making VR games significantly more interactive than standard video games. It is argued that such a high degree of interactivity and autonomy promotes a sense of presence within a 3-D digital world even when displayed via the medium of a 2-D computer monitor. Vince (1998) believes that such games must definitely be counted as VR systems since they employ the vital prerequisites of 3-D navigation and interaction.

In summary, immersion and presence are key elements of VR as they serve not only to define it but also to differentiate it from other computer software and video games. That immersion and presence are facilitated by increasing the sophistication and quality of interface devices cannot be disputed, though interactivity and autonomy also facilitate a sense of presence, helping users feel immersed in virtual worlds. Fully immersive VR systems isolate users from the real world and can be used to subject users to a wide range of sensory experiences, involving visual, auditory, haptic (tactile) and kinaesthetic sensations. However, such systems are out of reach of the majority of people and the technology, whilst constantly improving, as yet has failed to deliver on the promise of an experience so 'real' and 'intuitive' that the user no longer perceives the computer hardware. For instance, Blade and Padgett (2002) suggest that interface devices are still too primitive and that more sophisticated ways of getting information from the user's body to the host computer need to be devised. A possible approach could be that of tapping into the human nervous system in order to directly process the electrical signals emanating from it.

The less powerful alternative of desktop VR, on the other hand, does not harbour the same aspirations as its more expensive and complex fully immersive counterpart. Desktop VR does not isolate the user from the real world, nor does it utilise the range of interface devices available for use with immersive VR systems. It does, however, provide an interactive, navigable experience offering the user a degree of autonomy when interacting with the VE. In this respect desktop VE technology allows users to immerse themselves within a virtual environment by allowing them the facility to freely explore and interact with it, and thereby promoting, at least to some extent, the feeling of being virtually present. Moreover, an accumulating number of studies have demonstrated that information (for example, spatial information) acquired from a desktop VE will successfully transfer to real equivalent environments (eg. Foreman et al, 2003, 2005; Ruddle et al, 1997, Wilson 1999), reinforcing their authenticity.

How has VR been used?

Both desktop and fully immersive VR systems have been utilised as training and development tools in a range of settings including the military, aerospace, industry, education, medicine, retail and architecture. As mentioned above, BNFL initially had a new reactor control room modelled in VR and displayed on a desktop system in order to address any design problems at an early stage and offer staff training in the novel setting before the room was physically constructed. Similarly the Barclaycard finance company commissioned a simulation of a new headquarters building in order to allow their staff the opportunity to experience their new working environment prior to its being built. This also enabled staff to input ideas concerning layout, colour schemes and other design features (Vince, 1998).

In addition to the design of new commercial and residential buildings VEs have also been used in the design of heavy engineering structures such as petrochemical and hydroelectric plants (Stone, 2002) and gas compression platforms and production plants (Vince, 1998). Designing complex structures such as these utilising VR technology means that geometrically intensive CAD (Computer Aided Design) data can be converted into the more visually acceptable format of 3-D interactive simulations with behavioural capabilities (Stone, 2002).

In the retail industry, both immersive and non-immersive VR systems have been utilised in activities ranging from the assessment of consumer behaviour to the design of product packaging and the development of store sites and layouts. Stone (2002) reports that VR specialists such as Virtual Presence have collaborated with many retail and product development companies such as Sainsbury, Nestle, Lever, and Proctor and Gamble in the development of not only one-off VR environments but also in tailoring the development of VR design software packages specifically for the retail industry.

Medical and scientific applications for VR are also developing. In the area of medicine, surgical trainers such as MIST (Minimally Invasive Surgical Trainer) have proved successful to the extent that the MIST system, which allows medical staff to practice minimally invasive procedures, forms a core component for a number of medical courses (Stone, 1999). VR systems designed to aid medical staff analyse and diagnose movement disorders have also been developed. Kuhlen and Dohle (1995) describe such a system used to record patients' movements and play the trajectories back in 3-D allowing them to be viewed from any angle and be precisely quantified. Other areas of medicine that may benefit from the use of VR technologies include the training of impaired function, rehabilitation and motor learning (Holden and Todorov, 2002). Within clinical neuropsychology, VEs can be used to create dynamic 3-D stimulus presentations that allow clinicians to assess human cognitive and functional performance, providing novel forms of test protocol (Stirk and Foreman, 2005), and increasing standards of psychometric reliability and validity (Rizzo, Buckwalter, Neumann, Kesselman and Thiebaux, 1998). VEs have also been employed in the treatment of psychological disorders such as phobias, obsessive compulsive disorders, post traumatic stress disorder and autism (North, North and Coble 2002).

In scientific fields, VEs can and have been used to assist the visualisation and manipulation of a variety of processes and artefacts related to biology and physics. Included among these are drug chemical compositions, viral strains, protein chains, gaseous particles in motion, and a virtual wind tunnel (Stone, 2002). Educators have also utilised VEs to offer students more realistic and interactive learning paradigms than those offered by traditional methods. For instance virtual urban scenes have been used to help children learn foreign languages whilst children in 300 schools in Manchester have experienced virtual crime scenes (Stone, 2002). The Crime Conquest software, distributed free of charge by the Greater Manchester Police Authority, allows children to control the behaviour of virtual characters in the VE, for instance police, victim or witness and their decisions dictate how the scenario develops. The purpose is for children to better understand the roles played by the police, and educate them in what to do should they witness a crime, also to appreciate the consequences of criminal actions.

The above overview of some applications for VE technology is by no means comprehensive, though it does illustrate the wide variety of disciplines that have found a role for this relatively new technology. Many applications within psychological sciences will be reviewed below (see also Rose and Foreman, 1999), in particular the use of VEs to train spatial competencies. Outside psychology, this aspect of VE use has been found to be valuable in the training of staff in VE simulations of novel working environments, the training of surgeons operating on virtual bodies, pilots learning to fly and land at airports around the world from the safety of a flight simulator, and technicians learning to dismantle and reassemble military hardware by practice with virtual models, amongst others. These examples demonstrate the suitability of VEs as media for spatial cognition research and emphasise the need to make comparisons between real and virtual spatial learning and to investigate aspects of spatial-VE use such as the effects on spatial learning of activity and passivity when experiencing a VE.

Chapter 3

Experiment 1.

Transfer of spatial learning from virtual to real space in children: The effects of differential modes of exploration, age and familiarity

INTRODUCTION

Studies in real space - as opposed to virtual space - have indicated that active exploration of large-scale environments, described by Siegel and White (1975), as those that surround the individual and need to be comprehended via the adoption of various perspectives and by Kuipers (1978) as those that cannot be viewed simultaneously from a single-vantage-point, facilitates spatial learning. Piaget and Inhelder (1967) emphasised sensori-motor activities as an important part of spatial learning in children whilst Lee (1968) proposed that spatial representations manifest as the consequence of practical activity. Similarly, Siegel and White (1975) suggest that "actual locomotion" through space is an almost essential prerequisite for the formation of spatial representations. More recently, experiments have also indicated that active exploration of environments enhances performance on spatial tasks, particularly in children. For instance, Feldman and Acredolo (1979) found evidence to suggest that self-guided locomotion around an environment facilitates spatial memory in pre-schoolers. In their experiment, children in the 'active' condition who explored an unfamiliar hallway alone, were more accurate at subsequently relocating a lost object than children in the 'passive' condition who were accompanied by an adult during exploration. Herman (1980) found that 5 and 8 year-olds reconstructed a model town more accurately if they had walked through it rather than around it. Herman, Kolker & Shaw (1982) found evidence to suggest that 5 to 6 year-olds depend more on motor activity than do 8 to 9 year-olds when learning the position of landmarks in a novel environment. The findings of Benson and Uzgiris (1985) indicated that babies were less successful at finding a key in a box when they had previously been carried around it than if they had previously crawled around it.

Many of the studies indicating the importance of activity for spatial learning have also found evidence to suggest that, as humans get older they become less reliant on self-governed exploration to construct spatial representations. For instance, Herman (1980) found that fifth graders, aged 10 – 11 years, were more accurate on subsequent tests of spatial knowledge acquisition than kindergarteners, aged 5 - 6 years, regardless of active or passive engagement with a test environment. The findings of Siegel, Herman, Allen and Kirasic (1979) also suggest that older children are less reliant on active exploration to form cognitive maps than are younger children. They found that accuracy of construction, in an experiment utilising a small-scale model town, increased as a function of developmental level in addition to familiarity with the model and task. The findings of Feldman and Acredolo (1979), in their relocation of a lost object task, concur. They concluded that pre-operational children, aged 3 to 4 years, benefit far more from self-directed exploration than do concrete-operational children, aged 9 to 10 years, who due to their knowledge of projective and Euclidean space demonstrate increased capacity to efficiently encode spatial information regardless of mode of exploration. These studies and others support the developmental process proposed by Piaget and Inhelder (1967) who suggested that children have the ability to differentiate topological shapes at the pre-operational stage but are unable to represent projective shapes and concepts of Euclidean space until the concrete operational stage. Piaget (1968) also went on to suggest that as the most primitive form of memory, recognition memory depends mainly on sensori-motor schemata whilst higher level reconstructive spatial memory can be activated with much less stimulus support. Smothergill (1973) proposed that what he called "visual evocative memory" developed last. In essence free recall evocation memory refers to the ability to draw on mental spatial representations (perhaps in the form of a cognitive map) without the need for any present stimulus support. However, studies have also indicated that active exploration remains important for good spatial learning in adults. For example, Appleyard (1970) found that 80% of people, who commuted by bus, across a Venezuelan town, were unable to draw a coherent map of the roads on which they travelled. In contrast, the maps drawn by car drivers presented a continuous and coherent system. These findings were supported by those of Hart and Berzok (1982) who concluded that car passengers learn less about the spatial layout of a town than do drivers.

The last decade has seen a growth of interest in virtual reality (VR) as a tool for investigating spatial cognition. Defined as computer-generated, three-dimensional environments that people can explore and interact with in real time (Wilson 1999) VR offers many benefits for the study of spatial learning. For example, whilst it is difficult to control for all environmental parameters in real settings (Peruch and Gaunet 1998), VR allows the experimenter to extend laboratory levels of control whilst offering participants an experience more ecologically valid than any of the two-dimensional alternatives such as static photographs or non-interactive film. For instance, in VR it is possible for participants to explore entire buildings, in real time, while seated at a computer. In addition, experimenters can ensure that each participant is exposed to exactly the same visual stimulus while being able to manipulate the environment (for example, altering a building's architecture or the lighting) to explore the effects of various environmental features on spatial learning. Obviously, this order of control would be difficult to achieve in real world settings.

Despite obvious differences such as, narrow visual field, slow image rendering, optical distortions (Peruch and Gaunet 1998), and the lack of vestibular and tactile feedback (Wilson et al 1997) between virtual and real environments, studies have indicated that there exists considerable similarity between the spatial knowledge acquired from virtual and real experiences in particular of the kind required for navigation. For example, Stanton, Wilson & Foreman (1996) found that disabled children acquired detailed information about the spatial layouts of real buildings from the exploration of virtual simulations. In another experiment, Wilson, Foreman & Tlauka (1996) found that participants who explored a to-scale virtual rendition of a multi-story building performed at an equivalent level to participants who had explored the real building on a task requiring them to point to objects not visible from their current position. They concluded that learning in a VE could be transferred to the real world. Similarly, Ruddle, Payne and Jones (1997) who recreated in VR a real world experiment conducted by Thorndyke and Hayes-Roth (1982) concluded that participants who learn the layout of virtual buildings develop route and survey knowledge equivalent to that developed by people who learn their way around real buildings. Further evidence that children can also learn in a VE was indicated by McComas, Pivik and Laflamme (1998) who found that children trained in real space had no advantage over those trained in a VE on a location of hidden objects task.

Peruch & Gaunet (1998) reviewed much of the literature concerning VR and spatial learning and concluded that similar behaviours are generally observed in studies comparing real and virtual environments. However, despite a large amount of evidence indicating the equivalence of learning in real and virtual worlds, studies using VEs have not often indicated the beneficial effects of active exploration (Wilson, 1999; Peruch & Gaunet, 1998). For example, Wilson, Foreman, Gillett and Stanton (1997) found no evidence to suggest that psychologically active participants (i.e. directing the course of exploration) or motorically active participants (i.e. controlling the input device) gained any advantage in a task requiring them to point to objects not visible from their current location over passive-observer participants (i.e. those that had no influence at all on exploration). Similarly, Wilson (1999) reported that active participants were not superior to passive-observers on an orientation task and that there were no significant differences between the two groups on memory-for-objects tasks. In addition, Gaunet, Vidal, Kemeny and Berthoz (2001) reported that they could find no difference between participants who had actively explored a virtual town by directing movements along a series of streets, and passive participants who viewed a route imposed by the computer, on subsequent tests of spatial memory performance. In contrast however, the VR studies of Peruch, Vercher and Gauthier (1995) demonstrated that participants were better able to reach a specified unseen target using the most economical route after active exploration of a virtual environment than after passive observation of pre-recorded displacements. Whilst Farrell, Arnold, Pettifer, Adams, Graham and MacManamon (2003) found that participants who explored a VE actively either with or without the aid of a map were better at navigating around the equivalent real environment than passive VE explorers or naïve controls. Supporting data were also reported by Pugnetti, Mendozzi, Brooks, Attree, Barbieri, Alpini, Motta and Rose (1998) who found that both healthy participants and those with Multiple Sclerosis achieved better recall of the spatial layout of a VE after active exploration than did their passive counterparts. They did not, however, do better on a task requiring them to recall virtual objects they had encountered during exploration of the VE. Interestingly, Attree, Brooks, Rose, Andrews, Leadbetter and Clifford (1996) found that passive participants out-performed actives when recalling objects encountered during exploration of a VE but that active participants were better at recalling the spatial layout, although no differences were found for object location memory. Subsequently, Wilson (1999) failed to find a difference between active and passive participants when a spatial task was secondary to a memory-for-objects test. In this instance all participants were told they would be tested on the number of objects they remembered but not that their memory would also be tested for object location. Wilson concluded that procedural difference such as within-and-between-participant comparisons, measures of spatial learning, and type of task employed may affect the quantifiable benefits of active engagement in a virtual environment.

In summary, previous studies conducted in real space have, by and large, shown activity to be beneficial for spatial learning in both adults and children but more so for children. Yet despite studies indicating considerable similarities between virtual and real spaces, in terms of the spatial information they afford, studies in virtual space have seldom indicated an advantage for active explorers in terms of spatial learning. The predominant purpose of the current study is to investigate spatial learning after active and passive experiences of virtual environments, by drawing on the findings and methodological approaches of previous work set in both real and virtual space. In order to maximise the studies' potential of finding an active passive difference it was conceived that the experiment should partially replicate in VR a real world study that had yielded such a difference and in which children had participated.

To this end the current study utilised a VR town similar in design to the model-town used by Herman (1980). Herman ran a series of experiments investigating children's cognitive maps of large-scale environments. His participants (age range 5 to 9 years) were required to study a model town, either by walking within it, between the buildings, or walking around the perimeter from where all the buildings could be seen. They then had to reconstruct the model from memory and the accuracy of the reconstruction was used to evaluate the level of their spatial learning. Findings indicated that the children who actively walked within the town performed more accurately on the reconstruction task than those who viewed the town from around the perimeter. Herman concluded that traversing routes between landmarks within a spatial area is important for the development of cognitive maps and his findings have been cited in much of the subsequent work in the area as indicating the benefits of active exploration in spatial learning. In addition, Herman found that accuracy of performance improved as a function of age and number of trials completed.

'Active' participants in the current study used a joystick to navigate between and around the buildings within the VR model town, while in another condition participants viewed them from the perimeter. These conditions are equivalent to Herman's active and perimeter conditions mentioned above. However, the current study introduces a third 'passive' condition in which participants view, on a remote screen, the explorations of active participants with whom they are paired. If performance in the VE is equivalent to that in Herman's (1980) real world study active participants in the current study should outperform participants in the perimeter condition. It was also hypothesised that active explorers would outperform participants in the passive condition on subsequent tests of spatial learning. In addition it is hypothesised that the findings of the current study, if they further replicate those of Herman (1980), will show developmental effects (improvement with age) and practice effects, across trials, whilst also demonstrating that spatial learning in VR transfers to real-space.

METHOD

Participants

Eighty-six children participated, all attending the same London junior school provincial school in England. They were divided into 3 groups according to age (school year): 17 boys and 14 girls were from year two (6.1 - 7.3 years, mean 6.7), 14 boys and 12 girls from year three (7.4 - 8.4 years, mean 7.9) and 9 boys and 20 girls from year four (8.6 - 9.9 years, mean 9.3). All had normal or corrected-to-normal vision.

Setting

The school allowed the experimenter the use of a large classroom in which to run the study. The room, 10m wide by 15m long was lit with fluorescent lighting in addition to being well provided with natural light from a row of large windows at either end. At one end of the classroom, closest to the entrance was a carpeted "play area", devoid of any furniture, approximately four metres square. A vinyl floor plan of the virtual environment was placed in the middle of the carpeted area and all adjacent furniture moved back to a minimum distance of one metre (participants later placed models of objects they had encountered within the VE on this plan). At the opposite end of the classroom the computer system (on which participants would experience the VE) was set up on a work surface 70cms high. A screen effectively divided the classroom in two (front from back) and prevented participants seated at the computers from viewing the floor plan.

Materials

The virtual environment was created using SuperScape 3-D virtual reality software and was run on an IBM compatible desktop PC with a Pentium 3 processor simultaneously driving 2 colour VGA 14" monitors via a VGA signal splitter. Movement through the VE was controlled using a PC Line Tournament, six-button joystick allowing forward and backward movements and lateral translational movements.

A vinyl floor plan of the VE depicted a green rectangular area, nominally grass, bounded on all four sides and divided into four quadrants by grey roadways 10cms wide. The overall dimensions of the plan measured 200cms long by 180cms wide with the dimensions of each quadrant being 85cms long by 75cms wide; this layout was modelled on that used by Herman (1980).

Ten real models, representing objects encountered in the VE (eight buildings and two trees) were constructed to scale from modelling polystyrene card dressed with printed panels of the virtual objects taken from screenshots of the virtual buildings. These were designed to be used in conjunction with the plan described above to assess participants' spatial memory of the virtual environment layout. The three dimensional buildings were of various sizes and shapes and designated as: 'School' (20×15cms); 'Round Tower' (10×10cms); 'Purple Block' (10×10cms); 'Brick Block' (10×10cms); 'Apartment Block' (10×10cms); 'Shed' (5×7.5cms); 'Green House' (5×7.5cms) and 'Power Hill' (10×10cms). The trees, one totally bare of foliage and the other an autumnal Elm, were two- dimensional in that they were flat representations mounted on stands and both stood approximately 24cms high. Unlike the model buildings, these were not placed on the plan by the participants as part of their reconstructions of the VE but by the experimenter in advance of testing to be used by the participants as reference points.

The scale of the models and floor plan was calculated at 10:1 in relation to a birds-eye view screen shot of the VE (see Figure 3.1). This meant that one centimetre of real space model was equivalent to 1 millimetre of VE screenshot. This approach allowed the spatial relationships between the buildings in the VE to be translated into equivalent spatial relationships in real space independent of the arbitrary units of the 3-D software.

Figure 3.1: VE screenshot.

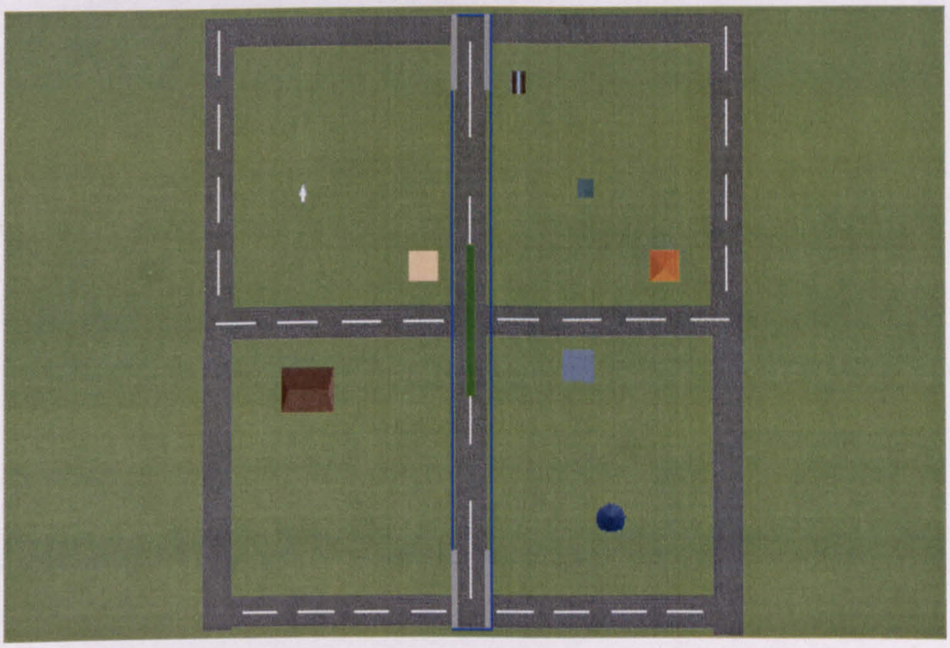


Figure 3.1, above shows a birds-eye-view screen shot of the VE explored by participants. Using this screen shot the experimenters were able to calculate the scale of the vinyl floor plan.

Metric scales, in centimetres, were placed along adjacent (bottom and left hand side) edges of the floor plan when birds-eye view photographs of each reconstruction were taken. This facilitated the subsequent calculation of the X and Y co-ordinates of object placements (see Figure 3.2 below). The photographs used for recording the participants' reconstructions of the VE were taken using a Konica 35mm compact camera with built in flash.

Figure 3.2: to-scale floor plan of the experimental VE

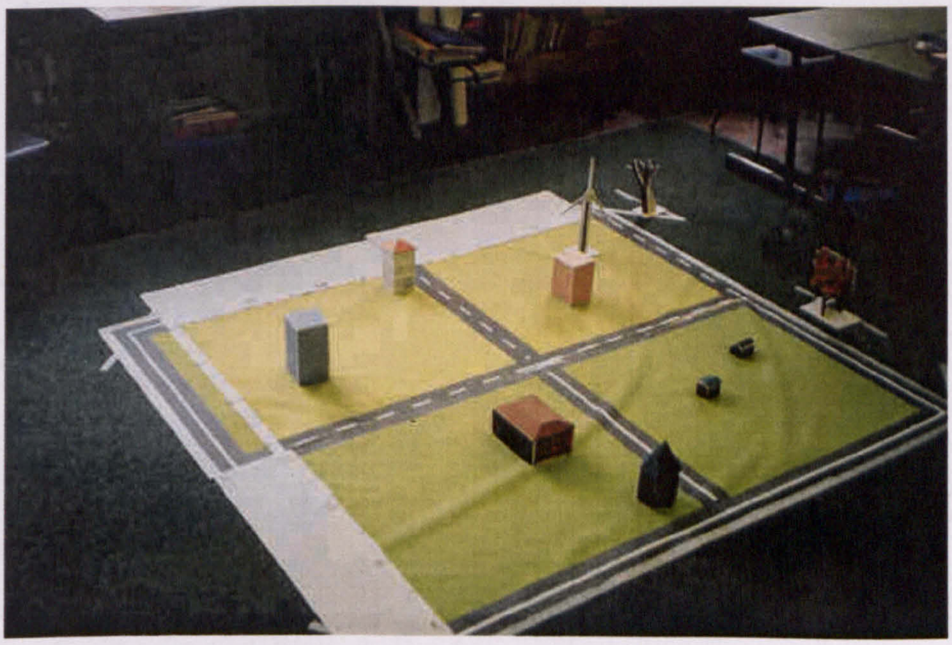


Figure 3.2, above shows the vinyl floor plan of the virtual environment on which participants placed models of the objects encountered within the VE.

Procedure

Children in the active and passive conditions were 'yoked' and participated in pairs matched for sex and class year. Children in the perimeter condition participated individually. Each participant experienced the to-be-learnt VE twice, reconstructing it in real space, using the plan and models described above, after each occasion, i.e. each participant had two trials. The trials were counter-balanced for order in the case of those that participated in pairs (active / passive condition) and counterbalanced for a 3 minute delay approximating that experienced by participants in pairs, in the case of those who participated individually (perimeter condition).

As participants entered the classroom their attention was directed to the bare floor plan of the VE. They were directed to stand in front of the floor plan (the South end) where their attention was guided to its features. They were told that the floor plan was like a map depicting a large green area (nominally grass) surrounded by roads on all four sides and divided into four smaller green areas by two roads that crossed over in the middle and that there were two trees at the end opposite to them (the North end). A point was made of emphasising the positioning of the trees in relation to the floor plan since they provided the most salient orienting features for subsequent re-constructions.

The children were then taken over to a table on which were placed the model buildings. To ensure that the children had no difficulty in recognising the real models from their virtual representations they were shown each individual virtual model on a computer screen easily visible from their position and asked to indicate the real space equivalent by pointing to it on the table. All of the children completed this task with ease.

Those children participating in pairs were then randomly allocated to either the active or passive condition and directed to sit at either the computer screen with the joystick in front of it (active station) or the adjacent remote screen with no joystick (passive station) (see Figure 3.3 below). Children allocated to the active condition were then asked if they were familiar with the joystick interface. If they indicated that they were not they were given some instruction with demonstration – "push the stick forward to move forward, pull it back to move backwards left to move left and right to move right "- which they all appeared to easily assimilate.

Figure 3.3: participants in the active and passive conditions

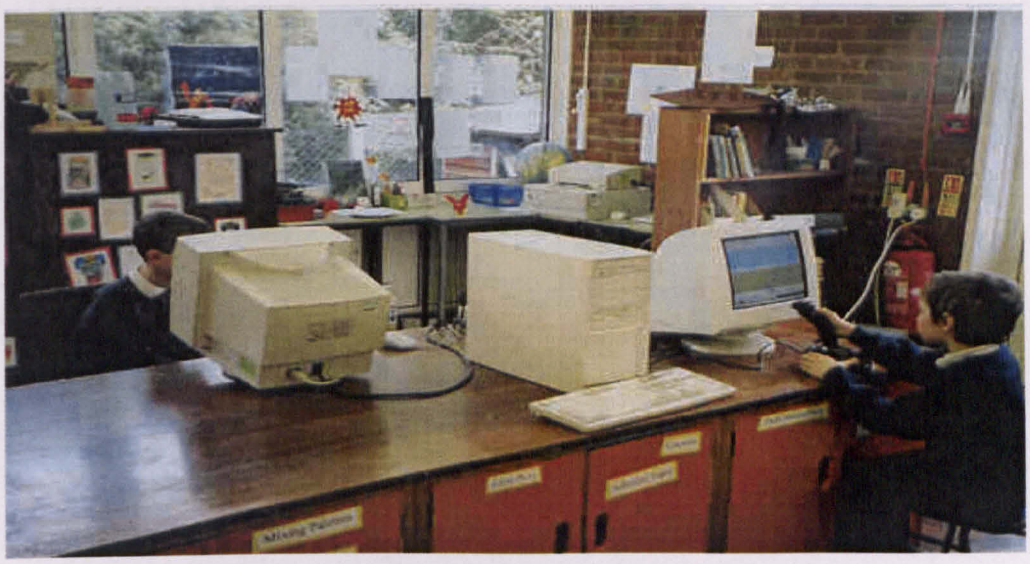


Figure 3.3, above shows participants viewing the virtual environment on computer monitors. The participant on the right is controlling the exploration of the environment via a joystick whilst the participant on the left is viewing the exploration on a remote monitor.

The children participating individually in the perimeter condition were simply asked to sit at a monitor with a keyboard in front of it after being shown the plan and identifying the models.

All the participants were informed that they were going to experience a computer representation of the floor plan they had been shown when entering the classroom on which would be virtual representations of the model buildings they had previously identified. Specifically they were told, " on the computer you are going to see the map (floor plan) that you were shown when you first came into the classroom and on that map you are going to see the buildings that you were shown on the computer screen. I want you to try and remember the positions of the buildings so that later you will be able to put the models that you pointed to on the table as accurately as possible in the same positions on the map at the front of the classroom as they are on the map on the computer". All the children indicated that they understood the task and subsequent observation of their behaviour confirmed this.

Participants in the active condition were told to "move around" the VE using the joystick so that they could have a "good look" at the positions of the buildings. They were also asked to indicate when they felt they were familiar with the VE and ready to reconstruct it in real space. The children in the passive condition were informed that they would be seeing exactly what their active counterparts were seeing and that it was important for them to concentrate on the VE in order to remember the positions of the buildings. Exploration time for both trials was limited to 2 minutes, although the need to enforce this limitation was never required. There were no limitations on reconstruction time.

Participants in the perimeter condition were given the same basic instructions as participants in the other two conditions in terms of experiencing the VE with a view to learning the positions of the buildings in order to reconstruct it as accurately as possible in real space later. However, they experienced the VE from eight preset viewpoints around the perimeter of the main square. Therefore they were not free to experience displacements through the VE between and around the buildings. Participants could switch between viewpoints, spaced 45 degrees apart, by using the number keys along the top of a QWERTY keyboard. Viewpoint 1 was from the South-end of the VE looking up the central road towards the trees at the North-end as illustrated in Figure 3.2 above. This was also the starting point for participants in the other conditions and the point from which all participants were shown the real-space floor plan. The viewpoints were numbered one to eight in an anti-clockwise direction around the VE and participants were encouraged to view the environment from all of them as many time as they liked. However, as with the other conditions, exploration time was limited to two minutes although there was never any need to enforce this limitation.

After each reconstruction, centimetre scales (as described above) were placed along adjacent edges of the floor plan (the South edge and the West edge) and birds eye view photographs of the model layout were taken from both the South and West sides of the model after which the model buildings would be removed and replaced on the table in readiness for the next trial.

Object placement accuracy, in terms of total distance-error-scores, was used to evaluate performance. This was calculated by transferring the model buildings' positions from the photographs to scaled graph paper printed with the correct building positions. The Measurements for each building were then taken from the diagonal centre of the 'child-placed' position to the diagonal centre of the true position. These distances were summed to give the total-distance-error scores reported in centimetres.

RESULTS

Descriptive Statistics

Table 3.1: descriptive statistics for trial 1 in terms of class year by experimental condition

Trial 1	Active condition			Passive condition			Perimeter condition		
	Mean	SD	N	Mean	SD	N	Mean	SD	N
Year 2	496.5	169.8	10	528.8	142.6	10	513.8	163.7	11
Year 3	418.4	185.6	10	411.1	92.3	10	421.1	156.2	6
Year 4	347.8	157.4	10	417.5	149.5	10	453.1	138.3	9

Table 3.1, above gives the mean placement error scores in centimetres with related standard deviations and sample sizes for trial 1 in terms of class year and experimental condition.

Table3.2: descriptive statistics for trial 2 in terms of class year by experimental condition

Trial 1	Active condition			Passive condition			Perimeter condition		
	Mean	SD	N	Mean	SD	N	Mean	SD	N
Year 2	479.7	174	10	304.3	116.2	10	359.3	165.3	11
Year 3	333.8	138.3	10	308.2	199.4	10	342.2	172.6	6
Year 4	253.8	215.2	10	188.7	82.1	10	312.5	159.2	9

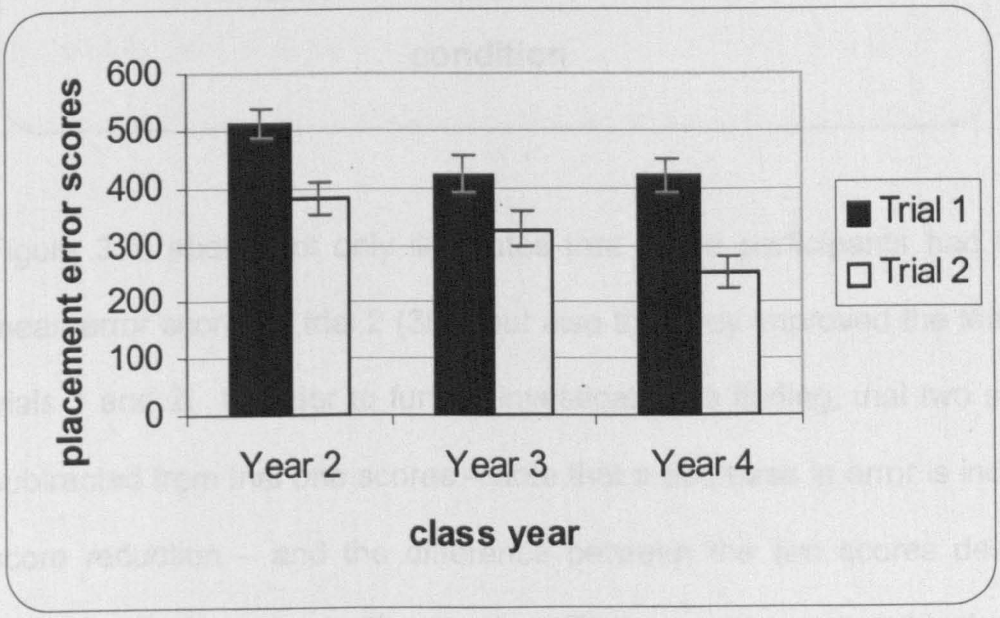
Table 3.2, above gives the mean placement error scores in centimetres with related standard deviations and sample sizes for trial 2 in terms of class year and experimental condition.

Inferential analysis

Placement error was the dependent variable in a 3 (class year (2,3 & 4)) X 3 (condition (active / passive / perimeter)) X 2 (trial (trial 1/ trial 2)) 3 way mixed factorial ANOVA with trial as the repeated measure.

The analysis revealed significant main effects for: trial, $F(1, 77) = 75.98$; $p < .01$(t1 mean 453; t2 mean 320) and class year, $F(2, 77) = 4.8$; $p = 0.01$. Post hoc Bonferroni multiple comparisons indicated that children in year 4 were significantly more accurate than were those in year 2, however year 3 children did not perform significantly differently from either year 2 or 4 children.

Figure 3.4: placement error scores for trials 1 and 2 by class year



As we can see from figure 3.4, above accuracy of constructions improved as a function of age with year four participants performing significantly more accurately than did year two participants across trials. However, we can also see that error reduction between trials one and two is approximately equivalent for all three age groups. A significant interaction between trial and condition was also revealed, $F(2, 77) = 5.84$; $p < .01$. Post-hoc paired samples t-tests indicated that placement accuracy improved significantly across trials for all conditions. However, independent samples t-tests indicated that placement accuracy of participants in the passive condition was significantly superior to those in the active condition at trial 2, $t = -1.98$, df 58, $p = .05$.

Figure 3.5: placement error scores for trials 1 and 2 by condition

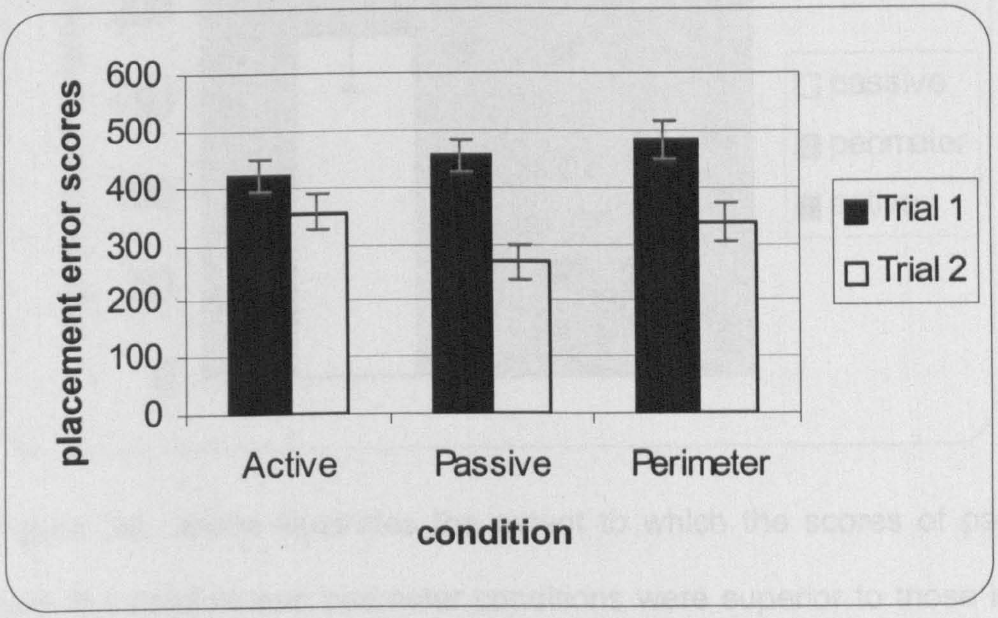


Figure 3.5, above not only illustrates that active participants had the highest mean error score for trial 2 (356) but also that they improved the least between trials 1 and 2. In order to further investigate this finding, trial two scores were subtracted from trial one scores – note that a decrease in error is indicated by a score reduction – and the difference between the two scores designated as 'learning' or 'improvement' scores'. These scores were subjected to a one-way ANOVA with condition being the between-subjects factor. In this instance there was a main effect for condition, $F(2,83) = 5.8$; $p < .01$. Bonferroni multiple comparisons indicated that passive participants' improvement scores were significantly higher than their active counterparts, $p < .01$. In addition the improvement scores of participants who viewed the VE from the perimeter were

arithmetically superior to the active participants' scores, approaching significance, p = 0.07. There was no significant effect for age here.

Figure 3.6: improvement scores by condition

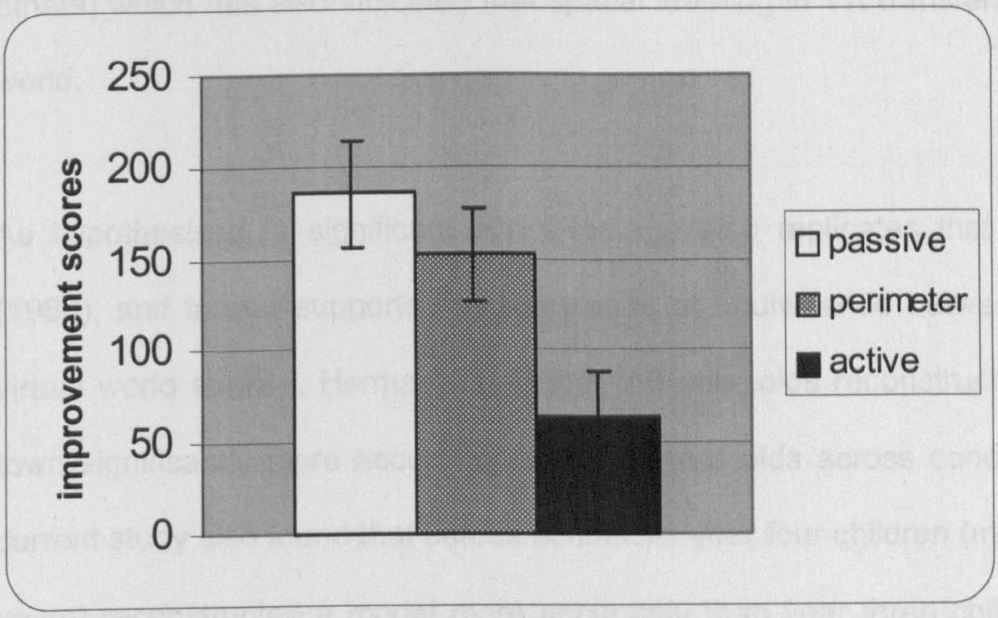


Figure 3.6, above illustrates the extent to which the scores of participants in both the passive and perimeter conditions were superior to those in the active condition.

DISCUSSION

Two of the experimental hypotheses were that: (1) spatial learning would transfer from virtual to real-space and that (2) the practice effects found by Herman (1980) would also be found by the current study. The significant result for trials indicates that the accuracy of participants at reconstructing the real-world model town significantly improved after the second exploration of the VE and supports hypothesis 2. This result also indicates that spatial learning has taken place and that participants were able to transfer this knowledge from the virtual reality model to its real-space equivalent thereby supporting hypothesis

1. This finding is in line with previous research in this area (Wilson, 1999; Peruch & Gaunet, 1998; Wilson, Tlauka and Foreman, 1998; Ruddle, Payne & Jones, 1997; Stanton, Wilson & Foreman, 1996; Tlauka & Wilson, 1996; and others) which has also indicated that spatial learning in VR transfers to the real world.

As hypothesised, a significant effect for age also replicates that of Herman (1980), and further supports the suggestion of equivalence between real and virtual world studies. Herman found that 8-9 year olds reconstructed a model town significantly more accurately than 5-6 year olds across conditions. The current study also found that across conditions year four children (mean age 9.3 years) reconstructed a model more accurately than year three children (mean age 7.9 years) and significantly more accurately than year two children (mean age 6.7 years) after exploring its VE equivalent. Indeed, inspection of Figure 3.4, above illustrates the almost linear relationship between age and accuracy on the model reconstruction task. It would therefore appear as if the developmental spatial competencies observed in real world studies also apply to VE based studies. The absence of a main effect for gender was also in line with the findings of Herman (1980, Experiment 2), and the hypothesis of the current study.

Up to this point the findings have supported our experimental hypotheses. They have indicated that spatial learning transfers from virtual to real space and that the practice, age and gender effects found in a study using an environment set in real-space are also found in a study using an equivalent virtual-space environment. This process of establishing equivalence between real and virtual world studies and the transfer of learning from virtual to real-space, has been undertaken in order to provide a strong foundation from which to examine the effects of active versus passive engagement with a virtual reality environment on spatial learning.

As discussed above, studies in real-space and established theories of cognitive development have indicated that spatial learning, particularly in children, is facilitated by active exploration of an environment. Therefore, given the current findings and those of previous studies such as McComas, Pivik and Laflamme (1998), who demonstrated that children with VR training were comparable to children trained in real space, one might also expect activity to be as advantageous in virtual space as it is in real space. However, despite the demonstrated equivalencies between the present findings and those of Herman (1980), as with previous studies in the area (Wilson, 1999; Peruch & Gaunet, 1998 and others) no advantage for active explorers over passive or perimeter observers was found. On the contrary, a significant trial by condition interaction indicated that whilst the scores of participants in all three conditions improved over trials, the scores of active participants improved the least across trials, the scores of participants in the passive condition showing the greatest decrease in error. These results indicate that passive participants were significantly more accurate at trial 2 than their active participant counterparts but only arithmetically superior to participants in the perimeter condition.

When learning (improvement) scores were calculated by subtracting trial 2 error-scores from trial 1 error-scores and analysed there was found to be a highly significant main effect for condition. Post hoc analysis indicated that passive participants' learning scores were significantly better than their active participant counterparts' but only arithmetically superior to perimeter participants' scores that were just short of being significantly superior to the scores of active participants.

A possible explanation for the finding, that passive participants improved to a greater extent than actives, might be that active-explorers learn less about the layout of a VE due to the extra cognitive effort required in using an unfamiliar input device (Arthur 1996). Passive participants in the current study could focus on viewing and learning the environment layout whilst the active participants' efforts were divided between operating the input device, making directional choices and the learning task. However, it would appear that this is precisely the kind of involvement with an environment that reinforces spatial learning in the real world. For instance, car drivers are thought to learn more about the layout of an environment than passengers (Appleyard, 1970; Hart and Berzok, 1982), yet it could be argued that driving is a far more complex operation than manipulating a simple input device. However, with the practice of months and years, for most people operating a car can become automatic, a matter of procedural memory and therefore requiring little cognitive effort. Ericsson and Delaney (1998) suggest that expert performance reduces the load on working memory through the automatisation of serial processes and this may help explain why experienced drivers are good at picking-up spatial information. However, in all probability inexperienced drivers who must attend to the task of driving would more than likely be found to be deficient at acquiring spatial information whilst driving. However, this hypothesis has yet to be fully tested, although some of the data presented here in Experiment 7 suggest that experienced drivers acquire more route knowledge than less experienced ones.

In terms of the current context we know that all the children involved in the study attended computer classes as part of their normal curriculum whilst anecdotal evidence indicated that many were computer, and / or computer game users outside of school. Added to which, of those few who indicated that they were unfamiliar with the simple joystick device all were easily able to use it after the minimum of instruction. This may indicate that use of the joystick in itself was not problematic but that the use to which it was employed – navigating through virtual space - interfered with spatial learning. Conversely passive participants benefited from experiencing the same visual flow as those in control of the displacements without the distraction of having to manipulate the input device or having to decide on what course of action to take in an unfamiliar situation. All of their attentional capacities could be focused on learning the spatial layout of the virtual environment.

An additional consideration is that the type of spatial information required by the participants to complete the test task was not of a wayfinding or route learning nature, both of which particularly benefit from active exploration (Siegel and White, 1975). Instead the task required participants to learn the relative positions of a number of landmarks. Siegel and White (1975) suggest that whilst routes are predominantly sensorimotor driven experiences, landmarks are primarily visually driven. That being the case it may be argued that navigating between the virtual buildings offered no advantage to the active explorers since the task – learning their relative positions – was predominately reliant on the visual modality, perhaps to the extent of making the motoric interaction redundant in terms of facilitating spatial learning under these conditions.

That being said, however, the extent of motoric interaction required to navigate a VE with a joystick may be inadequate to differentiate active participants from their passive counterparts particularly when both are viewing the same displacements with a view to learning the spatial layout of a VE. In contrast to the current study, Herman's (1980) participants walked between the model buildings or viewed them from the perimeter. Those who walked between buildings subsequently demonstrated a greater degree of spatial learning. Herman concluded that motor activity within a spatial area facilitates spatial learning. Therefore an additional issue to be considered in the current study is that the limited motor function required to use a joystick for navigation may not be as good at reinforcing spatial learning as a more gross and direct form of motoric interaction with an environment such as walking. This observation concurs with that of Wilson et al (1997) who suggested that the lack of vestibular and tactile feedback available to active explorers in VR might be a contributory factor to the differential results found in real and virtual space studies.

In many respects present findings concurred with those of previous studies utilising VEs and with those of Herman (1980), whose test environment was recreated as a VE. It was found that spatial learning transfers from real to virtual space and that the age, gender (no effect) and practice effects found in a real world study are also found in an equivalent virtual world study. However, the advantage for active explorers so often reported by studies conducted in real space such as Herman (1980) was not found here. However, neither was the equivalence of spatial learning between active explorers and passive observers reported by the vast majority of studies conducted in virtual space found here, instead a significant advantage for passive observers was found. This unexpected result is attributable to the possible combination of two or three contributory factors. Firstly, the spatial learning of active explorers was compromised since they experienced a larger cognitive loading than did their passive counterparts, due to the imposition of having to utilise the input device whilst making navigational decisions in unfamiliar space. Secondly, the task itself may not have particularly benefited from motoric interaction with the environment as it predominantly involved place learning as opposed to wayfinding or route learning. Thirdly, active participants' spatial learning may have been influenced by the lack of motoric effort required to navigate the VE with a joystick compared to more natural exploration such as locomotion. These factors combined may have led to passive observers having an advantage in terms of spatial learning over their active counterparts, and will need to be considered in any future studies in this area.

Flach (1990) also suggested that a range of variables could possibly account for the differences observed between active explorers and passive observers. These include control of attention [which may be influenced by cognitive loading], the kinds of information available and the kinds of activities involved. This assertion is to some extent supported by the findings of the current study, but the factors identified above as impacting on active / passive differences need to be further examined. To this end three suggestions are made for approaches that may address these issues.

1. Active explorers may be given prior training with the input device in virtual space in order to become more expert performers.

2. Passive observers may be required to perform a concurrent task estimated to load working memory to the same extent as active navigation in a VE.

3. Input devices could be used, which provide a more ecologically valid and motorically demanding form of interaction with the VE whilst not placing any extra burden on cognitive capacity.

It is hypothesised that either of the first two approaches would help reduce the effect of available cognitive capacity as an extraneous variable reducing spatial learning under experimental conditions. In other words differences in spatial learning would be due to the active passive dichotomy rather than differences in the utilisation of working memory capacity. This would mean that any advantage experienced by active explorers would not be lost against the advantage that passive observers have in terms of available cognitive capacity. Whilst the third approach could also help reduce the cognitive loading experienced by active participants, the extra motoric effort required would more closely resemble the effort required to move around in real space that is thought to be advantageous in terms of spatial learning.

Experiment 1(a).

INTRODUCTION

In Experiment 1 it was suggested that the type of spatial information required by participants to complete the test task should be taken into account when considering the findings since this particular task may not have particularly benefited from active exploration to the same extent as way-finding or route learning. The task required participants to learn the relative positions of a number of landmarks and it has been suggested that landmarks as specific patterns of perceptual events in a particular location are, for humans, predominantly visual as opposed to routes that are predominantly sensori-motor (Siegel and White, 1975). Interestingly anecdotal evidence from Herman (1980) supports this hypothesis. He reported that five of his participants (three, 5-6 year olds and two, 8-9 year olds) who stood at the starting point of the model town, but chose not to explore it, performed comparably to their peers. Herman concluded that exploration of the model town might not have been necessary because the children could view every building from any point within the model. This could also be said of the virtual model used in the previous experiment that was based on Herman's model. In order to test the hypothesis generated in Experiment 1, that the task and environment may have lent themselves to visual encoding rather than sensori-motor encoding, additional data were collected from participants who viewed the virtual model used in Experiment 1 from the start point only. From here all the buildings could be at least partially seen. If the environment and procedures in Experiment 1 lent themselves to predominantly visual encoding thereby minimising the possibility of demonstrating the benefits of activity within a VE, then it would follow that viewing the VE from a single viewpoint only should not be disadvantageous.

METHOD

Participants

Forty children, attending the same London junior school as participants in Experiment 1, aged 6-7 years old took part in the experiment. The 21 girls and 19 boys were all from class year two and all had normal or corrected to normal vision.

Setting

The school allowed the experimenter use of the same large classroom as in Experiment 1, above.

Materials

Exactly the same materials were used as in Experiment 1, above.

Procedure

All was exactly the same as described for Experiment 1, above with the exception that an additional, 'Single view-point' (SVP), condition was added. Participants in this additional condition were given the same basic instructions as participants in the other three conditions in terms of experiencing the VE with a view to learning the positions of the buildings in order to reconstruct it as accurately as possible in real space later. However, whereas participants in the active and passive conditions experienced the VE by travelling through it and participants in the perimeter condition experienced the VE from eight pre-set viewpoints around the perimeter of the VE, participants in the SVP condition experienced the VE from a single perspective. That is, they viewed the VE from viewpoint 1 of the perimeter condition only. From this viewpoint participants look from the south end of the VE towards the north, up the central roadway to the trees (see figure 3.1a). As with all the other conditions participants had two trials and were allowed to view the VE for up to 2 minutes per trial. Performance measures were as previously described.

Figure 3.1a: screenshot of VE viewpoint 1, looking from south to north.

Figure 3.1a, above shows viewpoint 1 of the perimeter-condition used in Experiment 1. As can be seen, all of the objects within the VE are visible from this perspective and it was potentially possible for participants in the SVP condition to learn the spatial layout of the VE from viewing this perspective only.

RESULTS

Descriptive Statistics

Table 3.1a: descriptive statistics for experimental condition by trial

	Active condition			Passive condition			Perimeter condition			Single view-point condition		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Trial 1	496.5	169.8	10	528.8	142.6	10	515.9	163.7	11	526.9	157.7	9
Trial2	479.7	174	10	304.3	116.2	10	359.3	165.3	11	339.9	102.3	9

Table 3.1a, above gives the mean placement error scores in centimetres with related standard deviations and sample sizes for trials 1 and 2 in terms of experimental condition. Class year was not a factor in this instance as all the participants attended year two and were 6 to 7 years old.

Mean placement error score was again the dependent variable in a 3 ('Condition' (active / passive / perimeter)) X 2 ('Gender' (male / female) X 2 ('Trial' (trial 1/ trial 2)) 3 way mixed factorial ANOVA with 'Trial' as the repeated measure.

The analysis revealed a significant main effect for: 'Trial', $F(1, 32) = 36$; $p < .01$ but not for 'Gender' or 'Condition' and a significant interaction effect for 'Trial' X 'Condition', $F(3, 32) = 4.0$; $p < .01$.

Figure 3.2a: condition by trial

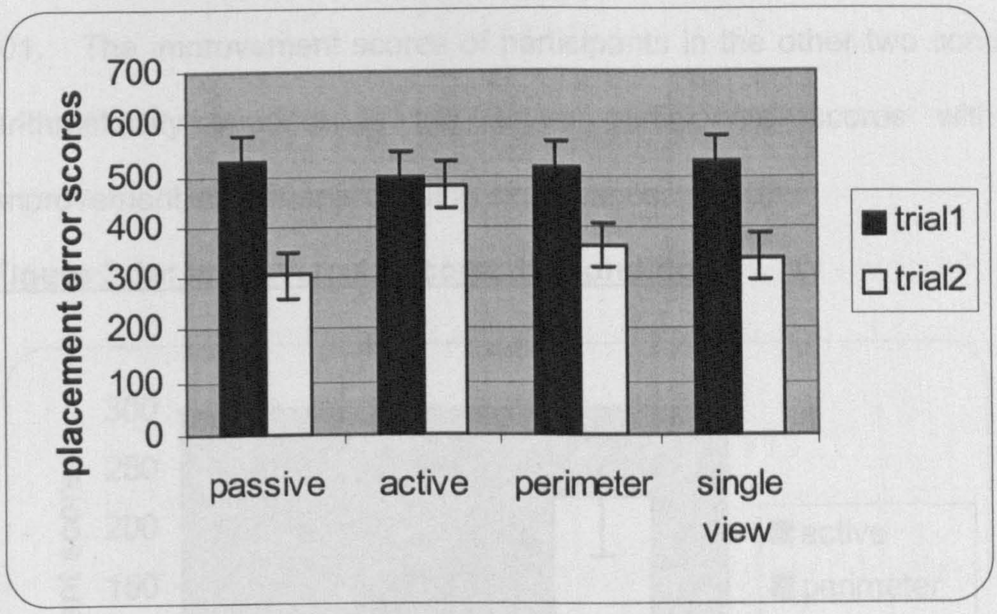


Figure 3.2a above illustrates the finding that active participant scores did not improve to the same extent as the scores of the participants in the other three conditions thus explaining the significant trial x condition effect.

For the interaction effect post-hoc paired samples t-tests revealed that active participants' error scores did not significantly improve across trials, $p > .05$ whilst the scores of participants in all other conditions did, $ps < .01$. In addition, independent group t-tests revealed that passive participant error scores were significantly lower than their Active participant counterparts at Trial 2, $p < .05$. Other comparisons were non-significant.

As in Experiment 1, improvement scores were calculated by subtracting trial two scores from trial one scores. The resulting data were then subjected to a one-way ANOVA with 'Condition' being the between-subjects factor. This analysis, as in experiment one yielded a main effect for condition, $F(3,36) = 4.4$; $p = .01$. Bonferroni multiple comparisons indicated that passive participants' improvement scores were significantly higher than their active counterparts, p = .01. The improvement scores of participants in the other two conditions were arithmetically superior to the active participants' scores with the SVP improvement scores approaching significance, p = .06.

Figure 3.3a: improvement scores by condition

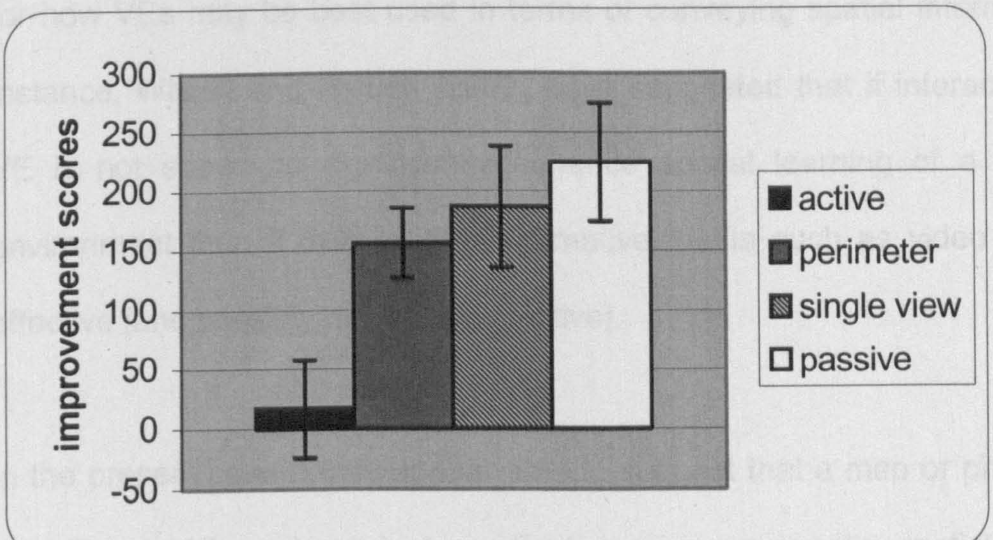


Figure 3.3a above again illustrates the extent to which active condition scores failed to improve across trials to the same extent as scores for the other three conditions.

DISCUSSION

The results of the present experiment support the hypothesis based on the findings of experiment 1 that viewing the virtual model from a single perspective would not disadvantageous in terms of subsequent tests of memory for spatial locations. The performance of participants in the SVP condition was statistically equivalent to the performance levels of participants in the other three conditions, all of which offered a greater degree of interactivity with the VE.

From the current findings it is possible to conclude that young children can learn the spatial layout of a VE by viewing it from a single viewpoint from which all of the objects within it can be at least partially seen. They can then transfer that learning to the real world just as effectively as children who have explored the same VE in a more interactive way can. This obviously has certain implications for how VEs may be best used in terms of conveying spatial information. For instance, Wilson and Peruch (2002) have suggested that if interactivity with a VE is not shown to significantly enhance spatial learning of a large scale environment then it may be that alternative media such as video are just as effective [and possibly more cost effective].

In the present case it may appear safe to suggest that a map or photograph of the VE would have been just as effective at conveying the spatial information required to reconstruct the real model, as interaction with the VE itself. However, it must be acknowledged that participants were able to reconstruct the real model from the same perspective from which they had experienced its virtual equivalent. Had they been required to perform some form of mental rotation in their reconstruction of the model, for instance asked to reconstruct the model after an imagined 180 degree rotation, the findings may have been very different. Arthur and Hancock (2001) report that response latencies to judge the layout accuracy of three object triads increased as a function of rotation angle for both map and static VE conditions (similar to the current SVP condition), but were not affected for a free navigation condition. The authors concluded that navigation within a VE could be similar to navigation in real space when unconstrained. The contrary nature of the current findings as compared with those of Arthur and Hancock (2001) could be explained by the observations made by Wilson and Peruch (2002) who proposed that diverse measures often lead to dissimilar outcomes with regard to active and passive experiences of VEs. These differences may be due to the fact that measures tap into different aspects of spatial cognition, or they may differ in sensitivity.

Despite the findings of this experiment supporting the hypothesis and demonstrating that the overall study design may not have been optimal in terms of demonstrating the benefits of activity, they do not explain why participants in the active condition did so poorly. The findings of Herman, Kolker and Shaw (1982) emphasise this point. They found that kindergarten children (mean age 5 years 7 months) who stood at the starting point of the same model as used by Herman (1980) were significantly less accurate at reconstructing the model than children who had moved through it either by walking or riding an experimenter-pulled wagon. They proposed that these findings supported their hypothesis that for younger children memory for spatial locations increased as a function of increasing motor activity. However, perhaps their hypothesis would have been more precise if it had stated that children's memory for spatial locations increased as a function of increasingly *familiar* motor activity. Another hypothesis generated by the findings of Experiment 1 was that active participants might have been poor at learning the spatial layout of the VE due to the extra cognitive effort necessary to use an unfamiliar input device. This issue is addressed in Experiment 2.

Chapter 4

Experiment 2.

The effect on children's' spatial learning of prior training in the use of an input device used to actively explore virtual environments

INTRODUCTION

One of the hypotheses generated from the findings of Experiment 1 was that active participants learnt less about the spatial layout of the VE than participants in the other conditions due to the cognitive effort required to use an unfamiliar input device to navigate virtual space. Whilst participants in the passive condition could concentrate all of their efforts on learning the spatial layout of the VE, active participants' efforts, who's displacements passive participants were viewing, were divided between the learning task and operating the input device whilst making directional choices. Similarly, participants in the perimeter condition who had only to push buttons to change their view of the VE, and participants in the SVP condition (Experiment 1a) who viewed it from a single perspective only, could focus all of their efforts on learning the spatial layout of the VE.

Active participants in previous real space studies that have indicated the benefits of activity in spatial learning for children, have either walked (Feldman and Acredolo, 1979; Herman, Kolker and Shaw, 1982; McComas, Dulberg and Latter, 1997 and others) or crawled (Benson and Uzgiris, 1985) whilst exploring their respective to-be-learned environments. Walking and crawling are obviously natural movements, which once mastered require little if any cognitive effort to reproduce allowing explorers to focus all of their cognitive abilities on learning the spatial layout of the environment they are in. Therefore, a major difference between being active in real space and active in virtual space is the mode of exploration and the relative cognitive effort required. For children in particular, if the mode of navigation is cognitively effortfull this might have a significant negative impact on their ability to encode the spatial layout of an environment.

Children may be more sensitive than adults to the deleterious effects actively navigating virtual space may have on spatial learning, due to the immaturity of their attention and working memory capabilities. For instance, Pascuell-Leone (1970) suggested that due to restricted working memory or 'M-space' capacity, children might be subject to severe limits in their ability to process information. Therefore a task, or as in Experiment 1, concurrent tasks requiring more information-processing capacity than is available will lead to failure or poor performance. By the same token, Case, Kurland and Goldberg (1982) suggest that one of the main maturational constraints is the size of the short-term storage space (STSS) available to a child for information processing. Arguing that attentional resources are limited, particularly for young children, and that these resources must be divided between information-processing and storage, Case et al (1982) propose that if resources are utilised to conduct difficult operations then less is available for storage of novel cognitions. Such a proposition supports the hypothesis generated by Experiment 1 and provides a possible explanation for why active participants were unable to form accurate spatial representations of the VE. Interestingly, Case et al (1982) also provide a possible explanation for older children's more accurate representations of the

VE layout, as indicated by Experiment 1. They propose that older children are more efficient at processing information than are younger children and therefore have greater capacity in reserve for storage.

Theorists have also suggested that working memory capacity as such may not be the cause of developmental differences on tests of concurrent tasks simultaneously requiring both processing and storage. For instance Cowan (1997) suggests that the critical variable changing with age could be the ability to carry out two tasks concurrently, not processing capacity or efficiency, and that this may depend on how competently focus of attention can be switched or divided between tasks. This theory could also account for the findings in Experiment 1 if one supposes that active participants found it difficult to divide or switch their focus of attention between the navigation and learning task and that this deficiency accounted for their poor performance. Indeed, Flach (1990) suggested that control of attention could be one of a range of variables possibly accounting for the differences observed between active explorers and passive observers. Alternatively, Bjorklund and Harnishfeger (1990) proposed that children are less able to inhibit irrelevant information from working memory and that this places extra demands on available storage space. This view has been supported by neurological studies such as that of Yakovelev and Lecours (1967) who found that the frontal lobes do not mature completely until adolescence, and Goldman-Rakic (1992) who found from studying the behaviour of brain damaged patients, that the frontal lobes are implicated in brain functions requiring the simultaneous holding and inhibiting of diverse information.

Despite the differing theories attempting to explain the specific mechanisms implicated in performance reduction, based on a limited capacity working memory paradigm (see Meadows, 1986; Baddeley, 1993; Cowan, 1997, for full reviews), what is generally accepted is that concurrent tasks can affect cognitive performance particularly in children whose working memory capacity or ability to fully utilise working memory function is immature. Baddeley, Lewis, Eldridge and Thomson (1984) suggest that the detrimental effect of an 'attention-demanding' secondary task on subsequent recall is extremely robust and consistent. The dual-task approach is the most commonly used paradigm for gauging resource demands on working memory (Guttentag, 1989) and has consistently indicated that as the demands of a particular task increase, performance on a concurrent task diminishes. This maxim was exemplified by the findings of Murdock (1965) who had participants learn a to-be-recalled list of unrelated words whilst performing card-sorting tasks of varying complexity. Murdock found that the number of words recalled from the list was inversely proportional to the difficulty of the particular card-sorting task being simultaneously attempted, i.e., as card sorting task difficulty increased that number of correctly recalled words decreased. Guttentag (1984) also found that the speed at which children tapped a computer keyboard key reduced by as much as 40% when they were required to concurrently learn a word list. Similarly, Miller, Seier, Probert and Ayers (1991) found that a secondary finger-tapping task was disrupted when young children were required to learn the spatial locations of a number of target pictures fitting into a particular category when presented along with pictures fitting into a different category. More specifically, in relation to navigation and wayfinding, Garden, Corwoldi and Logie (2002) found that both spatial tapping and articulatory suppression tasks interfered with the primary task of route learning from a segmented map (exp. 1) or in a real town centre (exp. 2). Interestingly however, whilst spatial tapping impaired the main task to a greater degree in experiment 1 it did so only for participants who had rated themselves highly on visuo-spatial abilities in experiment 2. Participants who did not rate themselves highly found that the articulatory suppression task caused more interference to their route learning ability. Garden et al (2002) concluded that whilst maps are an almost completely visuo-spatial medium real environments offer more varied cues to the different components of WM but high spatial ability participants still rely heavily on the visuo-spatial component of WM.

Even though there is much evidence to support the idea of a limited capacity working memory that affects human ability to efficiently perform concurrent tasks, there is also much evidence, both anecdotal and experimental, to suggest that it is possible for humans to overcome the limitations of working memory. Baddeley (1993) suggests that 'over-learning' may be a crucial factor in determining the extent to which concurrent tasks interfere with each other. For instance, anecdotal evidence would suggest that experienced drivers are able to maintain a conversation whilst simultaneously operating a vehicle and making traffic and route related decisions without apparent task interference, except in the most difficult of situations. However, for a novice driver, attempting the efficient operation of the vehicle may be the only task to which s/he is able to attend. Experimental evidence has also demonstrated that with sufficient training, humans are able to perform extremely complex concurrent tasks with minimal or no interference. For instance, Allport, Antonis and Reynolds (1972) had a number of skilled pianists sight-read and play a piece of music whilst simultaneously listening to and repeating back a continuous stream of prose. Similarly, Shaffer (1975) had a skilled typist copy type whilst also repeating back a continuous stream of prose. Both of these studies demonstrated that highly skilled subjects could perform concurrent tasks with minimal interference even when the tasks are not normally practised together. Taking this idea a step further Spelke, Hirst and Neisser (1976) trained their participants' to perform concurrent tasks in which they were not previously especially skilled. They found that after 20 weeks of practice participants could take dictation whilst reading and comprehending a story totally unrelated to the dictated material which they could also comprehend.

Training or over-learning on a task would therefore appear to reduce the cognitive effort required to perform that task thereby freeing up working memory / attention capacities to perform a concurrent task. This position is supported by the findings of Ericsson and Delaney (1998) who reviewed research on the effects of training on memory performance and, as mentioned above, came to the conclusion that expert performance reduces the load on working memory through the automatisation of serial processes. In fact Schneider and Shiffrin (1977) coined the phrase 'automaticity' to describe the absence of interference between the seemingly automatic performance of a well-trained or over-learnt task and concurrent activities, which they had observed in their studies.

As mentioned above, one of the hypotheses generated by the findings of Experiment 1 (current study) was that children in the active condition performed poorly, in terms of the subsequent measure of spatial learning, because in addition to the learning task, they experienced the extra cognitive load of having to utilise an unfamiliar mode of movement to navigate in an unfamiliar space. Therefore, unlike participants in the other conditions who were not distracted by a secondary task, the working memory of participants in the active condition was divided, and as shown by previous research (see above) without training, interference between concurrent tasks, particularly in children, detrimentally affects performance. The aim of the current experiment was to test the hypothesis generated by Experiment 1 by giving participants' prior training in the use of the input device to navigate the VE. The hypothesis is that familiarisation with use of the joystick will reduce the cognitive load on participants in the active condition who must use it to navigate within the VE. If the demands of using the joystick are eased, through the increased expertise acquired via training, then the performance of active participants on the spatial learning task should improve and be equivalent to, if not better than, the performance of participants in the passive condition.

METHOD

Participants

The participants were forty-two children (26 females and 16 males) aged between seven and eight years old and all in class year three of a London junior school. All had normal or corrected-to-normal vision.

Setting

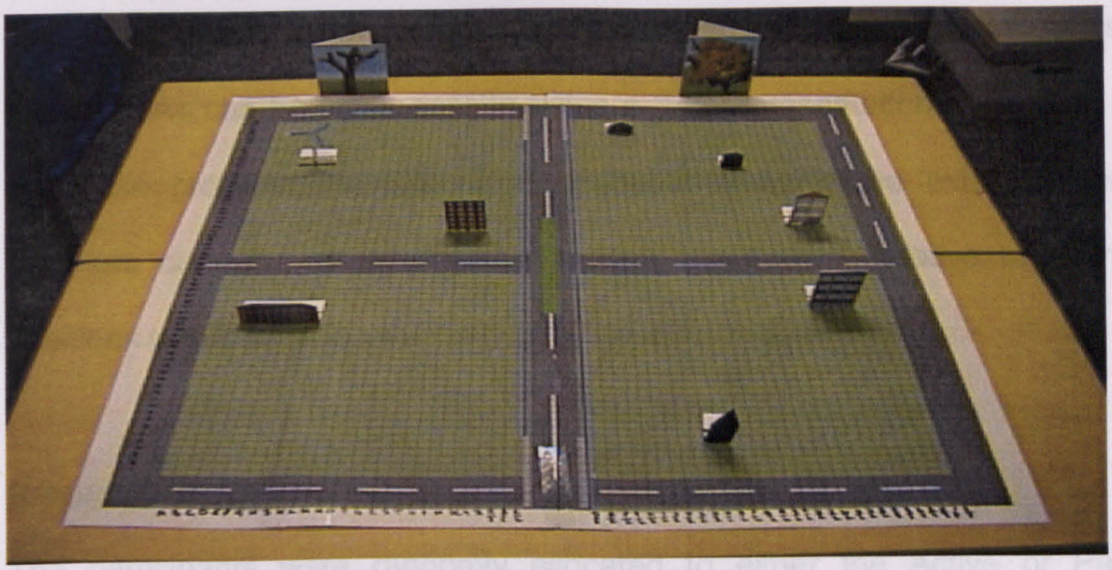
The school allowed the experimenters use of a classroom 4 metres square in which to conduct the study. The room, used to teach children with special educational needs, was well lit with fluorescent lighting but had no source of natural light. In the centre of the room were 2 tables, each 60 cms high and measuring 50x100 cms. These were pushed together to form a surface area of $1m^2$. A floor plan of the VE onto which participants placed models of objects they had encountered within the VE was placed on this surface. In a corner of the room, away from the floor plan the computer system on which participants would experience the VE was set-up on a computer desk. When sitting at the desk participants were facing away from the floor plan.

Materials

The VE as used in Experiments 1 and 1a (created using SuperScape 3-D virtual reality software) was run on an IBM compatible laptop computer (Toshiba Satellite Pro 4600) with a Pentium 3 processor. The visual display was presented via a 14-inch colour television monitor (Minoka MK 1499), with video in and video out facilities. Movement through the VE was controlled using a PC Line Tournament six-button joystick allowing forward and backward movements and lateral translational movements. The virtual exploratory displacements of participants in the active condition were recorded using a Sony Handycam Digital Video Recorder (9DV PAL).

As in Experiments 1 and 1a, a floor plan of the VE was used to evaluate spatial learning. However in this instance the plan was printed onto card with a 1cm X 1cm grid overlaid (see Figure 2.1, below). The overall dimensions of the plan measured 84cms long by 70cms wide with the dimensions of each quadrant being 36cms long by 31cms wide. The roadways were of a width of 4cms.

Figure 4.1: the floor plan of the VE used in Experiment 2



Picture 4.1, above shows the floor plan of the virtual environment on which participants placed models of the objects encountered within the VE. These are also shown in their correct positions.

The ten models used in Experiments 1 and 1a were recreated to a scale in keeping with the dimensions of the new floor plan. Images of the virtual objects were printed, mounted on card and cut to shape. These flat 2-dimensional models stood on to-scale bases in order to provide appropriately sized footprints. An example is shown in figure 4.2, below.

Figure 4.2: to-scale paper model of the 'school' building presented in the VE

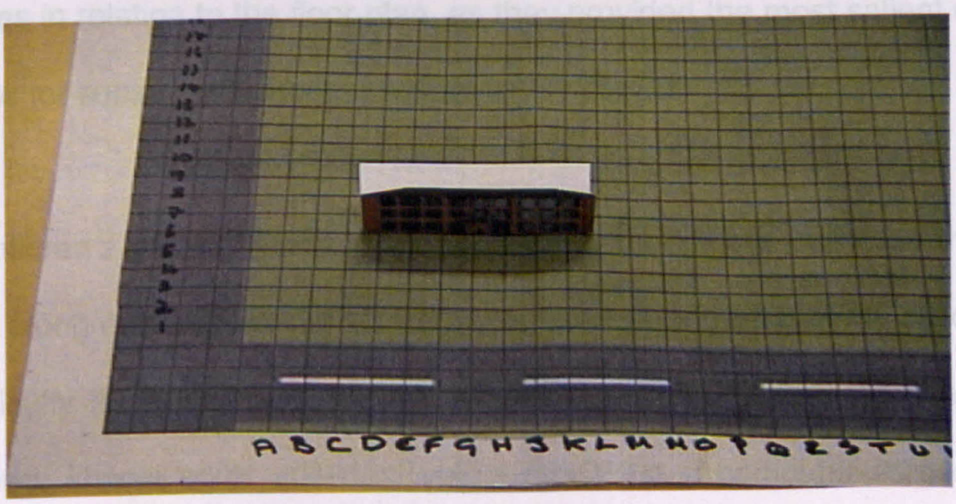


Figure 4.2 above, shows the model for the VR building designated as the 'school'. As can be seen, despite being a 2-D representation stuck onto card, the base provides the dimension of depth allowing the experimenters to calculate correctly the participants models placements relative to their true positions within the VE.

Procedure

The participants were randomly allocated to either the Active or Passive condition and participated individually. Each participant experienced the to-be-learnt VE twice, reconstructing it in real space (using the plan and models described above) after each occasion, i.e. each participant had two trials. The trials were counterbalanced for a one-minute delay so that the procedure more closely replicated that of Experiments 1 and 1a.

As in Experiments 1 and 1a, when each participant entered the classroom their attention was directed to the bare floor plan. They were directed to stand in front of the floor plan (the South end) where their attention was guided to its features. As in the previous studies, a point was made of emphasising the positioning of the trees in relation to the floor plan, as they provided the most salient orienting features for subsequent reconstructions.

The children's attention was then directed to the model buildings that were placed along one edge of the floor plan. In order to ensure that the children had no difficulty in recognising the real models from their virtual representations, they were shown each individual virtual model on a computer screen (easily visible from their position) and asked to indicate the real space equivalent by pointing to it on the table. All of the children completed this task with ease.

After the recognition task all participants were given five minutes of practice using the joystick to navigate around a VE. The practice VE consisted of a flat circular area on which were placed a number of unusual objects such as boats, planes, cars, statues and fairground rides arbitrarily selected and downloaded from the SuperScape virtual object warehouse. The participants were encouraged by the experimenter to navigate around the VE and look at as many of the objects as possible from as many different positions as possible in order to acclimatise themselves as much as possible to the 3-dimensional nature of virtual space and to get some real 'hands on' experience at using a joystick for the purpose of navigating around a VE.

After their 5 minute training session, participants were informed that they were going to experience a computer representation of the floor plan they had been shown when entering the classroom on which would be virtual representations of the model buildings they had previously identified. They were told to try and remember the positions of the virtual buildings so that they could put the model buildings in the correct places on the floor plan (for a more detailed description see Experiment 1). All the children indicated that they understood the task and subsequent observation of their behaviour confirmed this.

As mentioned above the children participated individually and not in 'yoked' active / passive pairs as in the previous studies. In this instance each active participant's explorations were taped and then viewed by the subsequent passive participant. Active participants were instructed to explore the VE for 2 minutes at trial 1and for 1 minute at trial 2. Passive participants were told that they would be watching a film of somebody exploring a VE. They watched the 2-minute exploration at trial 1 and the one-minute exploration at trial 2.

After each trial participants reconstructed the VE by placing models of the objects encountered within the VE on the floor plan. The experimenter recorded the positions of the participant placed objects by using the grid to note down their co-ordinates, using the centre of the object (diagonal intersection) as the reference point.

As in Experiments 1 and 1a, object placement accuracy, in terms of total distance-error-scores, was used to evaluate performance. This was calculated in centimetres by summing the distances between the centres of the participant-placed objects and their true positions on the floor plan.

RESULTS

Descriptive Statistics

Table 4.1: descriptive statistics for trial 1 in terms of gender by experimental condition

Trial One	Active condition			Passive condition		
	Mean.	SD	N	Mean	SD	N
Male	188.3	105.2	8	158.8	55.8	8
Female	172.3	53.2	12	150.5	75.3	14

Table 4.1 above, gives the mean placement error scores in centimetres with related standard deviations and sample sizes for trial 1 in terms of gender and experimental condition.

Table 4.2: descriptive statistics for trial two in terms of gender by experimental condition

Trial 2	Active condition			Passive condition		
	mean	SD	N	Mean	SD	N
Male	78.2	21.9	8	128.2	71.9	8
Female	121.7	80.3	12	137	88.8	14

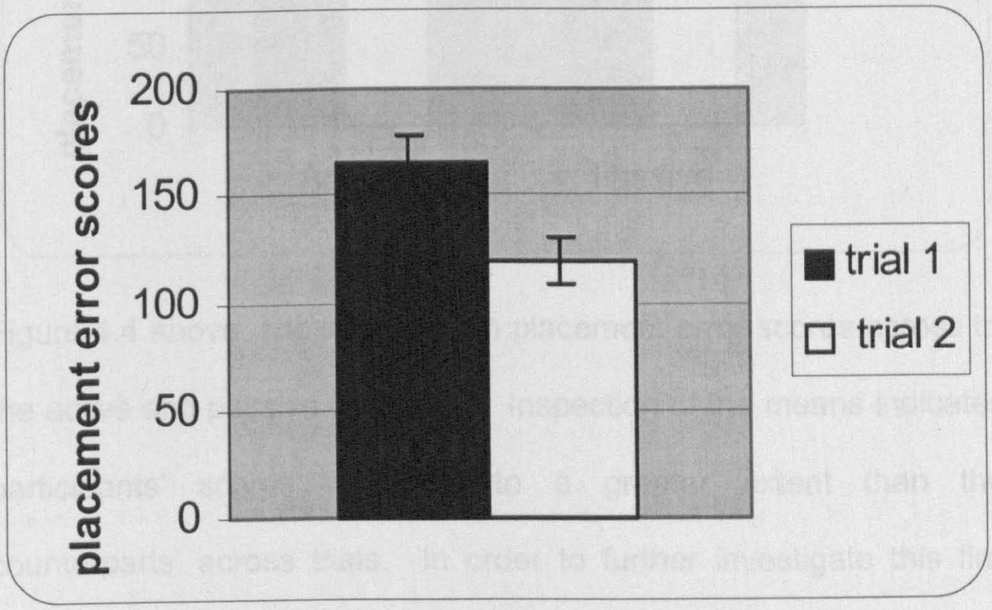
Table 4.2 above, gives the mean placement error scores in centimetres with related standard deviations and sample sizes for trial 2 in terms of gender and experimental condition.

Inferential analysis

Placement error scores were the dependent variable in a 2 (gender) X 2 ('Condition' (active / passive) X 2 ('Trial' (trial 1/ trial 2)) 3 way mixed factorial ANOVA with 'Trial' as the repeated measure.

The analysis revealed a significant main effect for: 'Trial', $F(1, 38) = 25.75$; $p < 0.01$(t1 mean 165; t2 mean 119). Inspection of the means indicates that participants' scores improved significantly from trial 1 to trial 2.

Figure 4.3: placement error scores for trials 1 and 2



As we can see from figure 4.3 above, accuracy of constructions improved significantly between trial 1 and trial 2 as evidenced by the reduction in error scores.

A significant interaction between 'Trial' and 'Condition' was also revealed, $F(1, 38) = 8.36$; $p < 0.01$. However, post-hoc paired samples t-tests indicated that placement accuracy improved significantly across trials for both conditions, whilst independent samples t-tests failed to indicate a significant advantage for either condition at either trial. Inspection of the means however, indicates that the scores of participants in the active condition improved to a greater extent across trials than did those in the passive condition.

Figure 4.4: placement error scores for trials 1 and 2 by condition

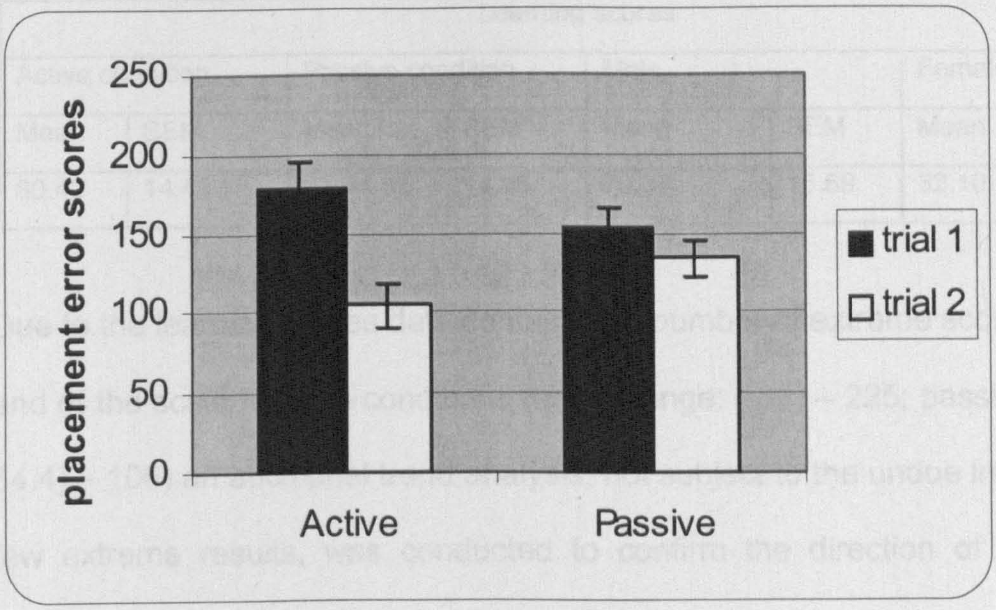


Figure 4.4 above, shows the mean placement error scores across trials for both the active and passive conditions. Inspection of the means indicates that active participants' scores improved to a greater extent than their passive counterparts' across trials. In order to further investigate this finding, trial 2 scores were subtracted from trial 1 scores – note that a decrease in error is indicated by a score reduction – the difference between the two scores yielding 'learning' or 'improvement' scores'. These scores were subjected to a one-way ANOVA with 'Condition' being the between-subjects factor (see table 3.2 for descriptive statistics). In this instance there was a significant a main effect for 'Condition', $F(1,38) = 8.36$; $p < .01$ and an effect approaching significance for 'Gender', $F(1,38) = 3.60$; $p < .07$. Inspection of the means (see table 3.2 below) indicates that active participants' learning scores were significantly superior to those of their passive counterparts', whilst male participants' learning scores were substantially, if not quite significantly, superior to their female counterparts scores. The analysis did not yield any Gender x Condition interaction effect indicating that both male and female active participants were superior to the respective passive counterparts.

Table 4.3: descriptive statistics for learning scores by experimental condition and gender.

Learning scores							
Active condition		Passive condition		Male		Female	
Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
80.42	14.49	22.04	14.06	70.37	15.89	32.10	12.48

Due to the learning scores data containing a number of extreme scores at either end of the scale for both conditions (active range: (-83) – 225; passive range: (-64.4) – 106) an additional trend analysis, not subject to the undue influence of a few extreme results, was conducted to confirm the direction of the results. Initial ranking of the data revealed that 80% of the best ten learning scores were achieved by participants in the active condition whilst 70% of the worst ten learning scores were achieved by participants in the passive condition. A Mann-Whitney test revealed these findings to be indicative of a highly significant group difference ($p < 0.01$, 1-tailed), with the value of the mean rankings indicating that the 'active' group scored more highly than the 'passive'.

DISCUSSION

As in Experiment 1 a significant effect for trial was revealed, indicating that the accuracy of participants' reconstructions improved across trials and that spatial learning, transferable to real space, had taken place. Also, as in Experiment 1 a significant trial by condition interaction was revealed and further explored by analysing learning scores that were calculated by subtracting trial 2 scores from trial 1 scores. The learning scores of active participants were significantly greater than those of their passive counterparts, indicating that the accuracy of their spatial representations improved to a significantly greater degree across trials.

The findings support the hypothesis that prior training in the use of the input device to navigate virtual space would lead to an increase in the spatial learning of participants using that device. In Experiment 1, active participants were given only brief instruction on how to use the joystick on the assumption that the use of such a simple device to navigate a simple VE would not be problematic. The results from Experiment 1, however, indicated that, contrary to the experimental hypothesis, active participants learned significantly less about the spatial layout of the VE than participants in the passive condition. In the current experiment participants received prior training in the use of the input device and this training appears to have facilitated active participants' spatial learning to the extent that they subsequently demonstrated significantly more accurate spatial knowledge concerning the layout of the VE than their passive counterparts, thereby reversing the trend indicated in Experiment 1.

So how has prior training that is relatively extensive (relative to that given to participants in Experiment 1) facilitated such a dramatic turn-around in the performance of active participants? In terms of a limited capacity working memory model as discussed above (see Introduction), it could be proposed that training has rendered the use of the joystick to navigate virtual space less cognitively effortful for active participants and thereby freeing-up processing and storage capacity for encoding the spatial layout of the VE. Following on from this position it could further be argued that, by reducing the cognitive effort required by participants to virtually-locomote through virtual space, the experimental task more closely resembles similar experimental tasks conducted in real space that have indicated the benefits of activity as described above (see Introduction, Experiment 1).

In particular the current findings now support those of Herman (1980), of whose study the current series of experiments are a partial replication and who found that activity within a real environment facilitates spatial learning of that environment. Experiment 1, while indicating equivalence between spatial learning in real and virtual space, and concurring with Herman's other findings concerning age and practice effects, did not replicate his findings indicating the benefits of activity. However, whilst Herman's active participants walked around a real to-be-learned environment, participants in the current study had to use a joystick to explore an equivalent virtual to-be-learned environment.

While many studies have shown that the spatial learning obtained from VEs can be equivalent to that obtained in real space (see Introduction Experiment 1) it is also undoubtedly true that virtual space is different from real space and the experience of exploring virtual space, therefore different from that of exploring real space (Peruch and Gaunet, 1998). These differences must affect learning. For instance, McComas, Pivik and LaFlamme (1998) reported that children with VE training performed comparably to children trained in the equivalent real environment but only after three practice trials, before which real environment trained children were superior. These findings could be interpreted as indicating that whilst equivalent real and virtual environments offer equivalent spatial information this information may not be as readily available to explorers of virtual space as it is to explorers of real space. This may be because explorers of virtual space must first adjust to mode of exploration (i.e. type of input device) and the type of space being explored (i.e. virtual space) whereas explorers of real space are already familiar with the mode of exploration (i.e. walking) and the world in which they find themselves, if not the particular environment.

The observation of Satalich (1995) that VE training may not be advantageous over map training unless trainees have a minimum of 4-6 hours VR experience, demonstrates the qualitative differences between real and virtual media, and that whilst VEs can offer significant levels of spatial information, people need time to acclimatise to the unique properties of environments created with virtual reality software. Evidence suggesting that, initially at least, active exploration of a VE can have disorientating effects was presented by Arthur and Hancock (2001) who found that activity led to more robust knowledge of the spatial layout of a VE, but that participants took significantly longer to learn the layout when compared to participants who either experienced the layout in map or static VE (i.e. a single screen shot) form.

Without training, even adult active explorers of virtual space may be more prone to disorientation and less able to learn the layout of a VE than non-interactive (passive) observers of VE images who may be spared initial disorientation because they view the virtual experience as purely televisual, a medium with which they are probably very familiar. However, once active explorers are able to reconcile themselves with use of the input device and orient themselves within a VE it may be that they are in a better position to learn a VE's spatial layout than are passive viewers.

Despite evidence suggesting that actively exploring virtual worlds and simultaneously encoding their spatial layouts may be difficult regardless of developmental level, for VR-naive children, due to their cognitive immaturity and the maturational constraints of working memory, it may be particularly challenging, as indicated by the findings of Experiment 1. However, their very immaturity is also what makes activity particularly beneficial for children in terms of spatial learning. Siegel and White (1975) who summarised theories, models and studies concerned with spatial cognition concluded that for children the development of spatial representations is greatly facilitated by and possibly even dependent on actively moving through the environment. Subsequent real space studies, such as those mentioned above have tended to support this hypothesis by demonstrating the benefits of activity for children and also how the benefits decrease as developmental level increases (see Introduction Experiment 1 for a fuller account).

As mentioned above, with the exception of a few unreplicated examples, VE studies have generally not demonstrated the benefits of activity in terms of spatial learning. In fact, by and large, these studies have found no difference, on subsequent tests of spatial learning between participants who have actively explored VEs and those who have viewed them passively. However, these studies have all, to the knowledge of the author, been conducted with adult participants and since adults are not as dependent as children on activity for spatial learning and are generally speaking cognitively more mature than children, the detrimental effects of concurrently navigating a VE and learning its layout without sufficient training may be not as exaggerated, i.e., adults do not demonstrate the benefits of activity but neither is their spatial learning as debilitated by the concurrent tasks as is that of children. However, it might be that any demonstrable advantage experienced by adult active explorers of VEs over their passive counterparts is masked by the extra cognitive load of performing the concurrent tasks of navigating and learning the spatial layout of a VE.

Summary of Experiments 1 and 2

In addition to demonstrating that the age and practice effects found in real space studies are also found in virtual space studies, and confirming that spatial learning transfers from virtual to real space, the current series of experiments has also demonstrated that children who actively explore VEs can learn more about the spatial layout of those VEs than those that view them passively. However, this appears only to be the case if sufficient prior training is provided in the use of the input device and experience of using it in virtual space is given before exploration of the test environment. If adequate training is not provided then it appears that passive observers have an advantage in terms of spatial learning since they do not have to perform concurrent tasks i.e. both navigating and learning the layout of the VE. Therefore, training appears to allow active participants to devote more of their attentional resources to learning the layout of a VE, thereby demonstrating the benefits of activity in virtual space as they would in real space. These findings have important implications for the future of VEs as a training and remediation media, not only for children but also for adults. In particular future research should focus on defining effective training strategies for non-specialist users of VEs since training appears to have a significant effect on what is acquired from virtual experiences.

Chapter 5

Experiment 3.

Does increasing motor demand whilst simultaneously reducing cognitive effort lead to more accurate distance estimations in VEs?

INTRODUCTION

The findings of Experiment 1 – that passive observers learned more about the spatial layout of an experimental virtual environment (VE) than did active explorers - raised the question of what effect, if any the input device might have on spatial learning. It was hypothesised that an input device could be detrimental for spatial learning if the user's attentional capacities were divided between using an unfamiliar device to explore a VE whilst concurrently attempting to learn the layout of the VE. This hypothesis was subsequently supported by the findings of Experiment 2, in which active explorers demonstrated superior spatial knowledge than their passive counterparts of the same experimental VE as used in Experiment 1, after they had received extended training using the input device. The extended training was hypothesised to have reduced the load on working memory required to use the input device thereby allowing active participants to focus more of their attentional resources on learning the layout of the VE (see Experiments 1 and 2 for full details).

In addition to competing for limited working memory resources it was also hypothesised that the input device used in Experiment 1 – a standard joystick – required insufficient physical effort from the user to initiate and perpetuate virtual movement and was therefore inefficient for reinforcing the user's spatial learning. Input devices or locomotion interfaces have been categorised as active or passive (Durlach and Mavor, 1995). Joysticks and similar devices that allow the user to move through a VE without significant exertion are classified as passive locomotion interface devices. Conversely devices requiring the user to utilise significant effort and repetitive limb motion such as gait, replicating the action required for movement through real space to achieve virtual motion, have been designated as active locomotion input devices.

In the real world, active exploration of an environment is generally associated with walking or perhaps cycling, both of which demand significant physical effort to achieve. Furthermore, whilst the demands of driving may be less physically demanding, the sensations of acceleration and deceleration associated with the physical inputs to vehicular controls are also greater than any sensation associated with manipulating a joystick. In real environments, it is widely believed that active exploration enables a superior level of spatial learning than passive exploration, because activity provides reafferent feedback on movement-contingent changes in the visual world, which are arguably necessary inputs for spatial processing in 'spatial' brain structures (O'Keefe and Nadel, 1978). However, it is debatable if this level of feedback is sufficiently available to users of passive computer input devices and if it is not, this could be a contributory factor for the lack of active / passive differences found by studies using VR to investigate spatial learning.

Wilson, Foreman, & Tlauka (1997), have suggested that a contributory factor to the differential results found between real and virtual space studies may be that active explorers in VR do not benefit from the vestibular and tactile [proprioceptive and kinaesthetic] feedback available to active explorers in the real world (for a review of these studies see the Introduction to Experiment 1). Evidence to support this assertion is provided by the findings of Bakker, Werkohoven and Passenier (1999), that participants who effected rotational movement in a VE by using their legs to turn around their axis were significantly more accurate on a path integration task than participants who initiated virtual movement via a space-ball (a type of joystick device) or seated on a rotating platform which they controlled via an electric motor. They concluded that the kinesthetic feedback from leg movement combined with vestibular and visual stimulus provides more reliable and accurate information for path integration than either visual feedback alone or vestibular and visual feedback. Furthermore, Rosebrock and Vamplew (1999) found that when participants were tethered to simulate self-motion during exploration of a spatial maze, the simulation of actual movement- "steps"- resulted in their acquiring better spatial memory than did those using the more conventional flying mode. As Rosebrock and Vamplew (1999) point out, *"... flying through an environment may well give a different perspective and less detailed knowledge of the environment than that which can be acquired by preparing the body to 'walk' through it"* (pp. 408-9). Chance, Gaunet, Beall and Loomis (1998) also found that virtual exploration controlled via an interface driven by natural walking was advantageous for orientation over the use of a passive input device. However, their findings were not consistent across all sessions. Similarly Bailey and Witmer (1994) found that higher levels of interactive exposure to a VE led to better configurational knowledge, but not under all conditions. In their study participants' field of view (FOV) was linked to body orientation only (uncoupled), or more interactively, with both body and head orientation (coupled). They found that participants' configurational knowledge was best when their explorations were guided and FOV control was coupled, or free but uncoupled. They suggest that free exploring participants with coupled head tracking may shift their gaze too quickly for the virtual scenes to be updated at an appropriate speed and that this could have a disruptive effect on the efficient acquisition of the configuration of the virtual environment.

Of interest in the current experiment is the effect on spatial learning of an input device reliant on gait to achieve movement through a VE. Such a device theoretically offers two advantages over a passive joystick input device, both of which should be beneficial for spatial learning. Firstly, since the action of walking is, for most people subject to automatic processes it requires little if any cognitive effort, thereby allowing participants to focus all of their mental efforts on viewing the VE. Secondly, the physical action of walking required by such an input device to maintain motion through the VE should facilitate spatial processing via reafferent feedback based on kinaesthetic information. However, due to the technical limitations of the gait-dependent active locomotion interface available to the author, only straight-line movement through the experimental VE was possible. Therefore, the current experiment utilises only distance estimates as the measure of participants' spatial learning. Obviously being able to judge distances between objects is essential for the accurate mapping, mental or otherwise of any environment, virtual or real.

Participants exploring VEs invariably underestimate distances among objects and the distances they have themselves covered during their exploratory displacements (Hayashibe, 2002; Henry and Furness, 1993; Kline, 2000; Ruddle, Payne and Jones, 1997; Witmer and Sadowski, 1998). In both indoor and outdoor space depictions, virtual reality experience and passive observation of video-recorded routes gave rise to distance underestimates, compared with real exploration (Hayashibe, 2002). Witmer and Sadowski (1998) found that participants asked to walk without vision to a target after viewing it in reality or in a VE would underestimate by 8% following real observation but by 15% following virtual viewing. In a series of studies in which traversed distances of between 3.5m and 93m in VEs had to be reproduced in equivalent real spaces, underestimation was consistently observed, although it could be influenced by such factors as speed of movement (Kline, 2000).

The underestimation effect in VEs is surprising, given the effectiveness of VEs in imparting spatial information, since distance estimation might be regarded as essential to the successful navigation of spaces (Kline, 2000, see Waller, Loomis, Golledge and Beall, 2000). Although poor spatial orientation has been reported when participants use head-immersion equipment and navigate very large environments with interconnected spaces (Darken and Silbert, 1996), in many studies using desk-top presentation, and involving old and young, disabled or able-bodied participants, following exploration and spatial training in a VE, participants typically showed a substantial ability to locate places, take routes between targets, point in the direction of obscured landmarks, and draw survey maps, when tested in the real equivalent environment (Foreman et al, 2003, 2005; Foreman, Stirk, Pohl, Mandelkow, Lehnung, Herzog and Leplow, 2000; McComas, Pivik, and Laflamme, 1998; Richardson, Montello and Hegarty, 1999; Waller,.2000; Waller, Knapp and Hunt, 2001; Wilson, 1999), reinforcing the suitability of VEs as spatial training media (eg. Bliss, Tidwell and Guest,1997; Foster, Wenn and Harwin, 1998; Rose and Foreman, 1999; Rossano, West, Robertson, Wayne and Chase, 1999; Tate, Silbert and King, 1997; Wilson, 1997). The authenticity of virtual experience is further indicated by the fact that standard metric effects observed in real world distance estimation studies, such as the exaggeration of distances travelled in zig-zagging routes compared with straight routes of the same length (Sadalla and Magel, 1980), can be reproduced effectively using a VE (Jansen-Osmann and Berendt, 2002).

A factor that might be expected to influence the acquisition of spatial information from a VE is the active or passive status of the participant. However, in studies using VE training, passive participants who observe the performance of an active explorer seem to acquire as much spatial information as if they controlled the input device themselves (Sandamas and Foreman, 2004; Wilson, Foreman, Gillett and Stanton, 1997; see Peruch and Gaunet, 1998 for a discussion).

Displacements in virtual space produce changes in screen images that equate to what Gibson (1966) called "optic flow", in particular the central-to-peripheral migration and increasing retinal dimensions of objects in a space as an individual passes through it. When such optical changes are consistent with intended displacements by the active participant, this might be expected to generate a more accurate representation of distance travelled than for a passive observer. On the other hand, Hayashibe (2002) has found that distance underestimation occurs similarly after VE exploration and passive observation of video-recorded routes.

The present experiment used a simulation of a corridor, containing 3 distinctive objects. Participants passed along the corridor, passing the 3 objects in, walking, flying or passive-walking or passive-flying modes. They then had to indicate the locations of the 3 objects in a real equivalent corridor. It was expected that while underestimation of distances would be the norm, and that the greater the estimated distance the greater the underestimation, those in active conditions would make more accurate estimations (distance from the starting point) than those in passive conditions, and that the active walking group would make more accurate judgements than those in active flying mode. Half of each group was male, half female, allowing us to examine the generality of Astur, Ortiz and Sutherland's (1998) conclusion, that gender differences in spatial performance emerge particularly clearly when participants are tested in VEs.

METHOD

Participants

Participants were 40 undergraduate students, 20 male and 20 female. All were between 18 and 23 years of age and had normal or corrected-to-normal vision. They were randomly allocated to the four conditions (active-walking, active-flying, passive-walking and passive-flying; hereafter A-W, A-F, P-W and P-F respectively) with the constraint that half of each group were male. They were tested in A-W, P-W and A-F, P-F yoked same gender pairs.

Apparatus

The virtual environment was constructed using Superscape VRT software (version 5.0), and displayed using a standard IBM pc, with a Pentium IV processor. The image was projected on to a 4m x 3m screen, via a standard RGB projector, the screen being 5 m from the projector. The image was projected over the heads of the participant pair and a single overhead strip light provided lighting in the room, so that room illumination was low. The viewpoint in the VE was set at 170 cm (approximately average human eye height).

As illustrated by Figure 5.1 below, the virtual corridor environment consisted of walls and ceiling coloured a homogeneous cream colour and a floor having a light brown parquet texturing. There were no doors and windows depicted. The three objects were placed to the right of the corridor at virtual floor level, and consisted of green, red and blue flower pots respectively, their virtual height and width being 45cm x 20cm. The distances from a visible starting line at the near end of the corridor to the three objects (using a conventional scale) were 12.2 m, 30.5 m and 36.6 m.

Figure 5.1: the virtual corridor

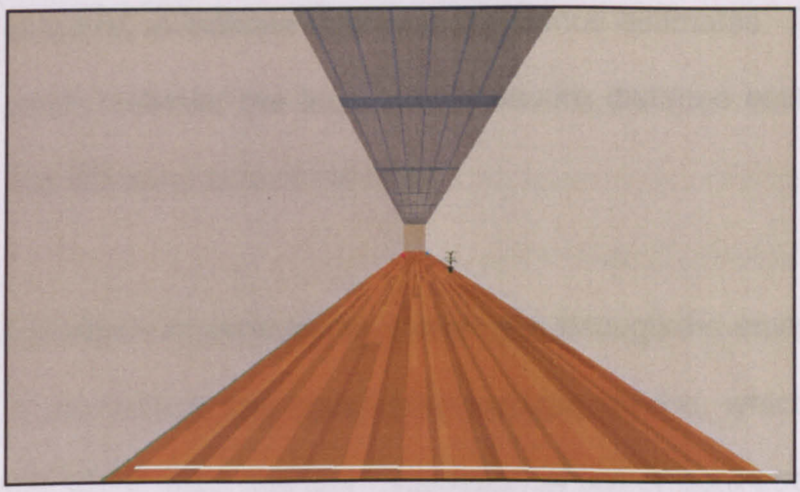


Figure 5.1, above shows the virtual corridor explored by participants. In the foreground can be seen the start line and in the distance can be seen the objects. The closest one is on the right.

In the real corridor, there were a number of windows, doors, and wall notices that were not present in the VE. The floor of the real corridor had a wooden parquet surface (see figure 5.2 below).

Figure 5.2: the real corridor

Figure 5.2, above shows the real corridor along which participants were required to indicate their object distance estimates. The start line is just out of view, however the tape used measure distance estimates can be seen along the left-hand side of the floor.

For the A-W participants, movement through the environment was produced via a proprietary two pedal step-exercise device, which was interfaced with the computer such that the depression of left or right pad produced a 0.5 m virtual forward movement (see Figure 5.3). The device was set at the least effortful setting, so that the pads could be depressed successively with minimum opposing force, to simulate normal walking movements. For A-F participants, depression of the forward directional keyboard key produced a movement of 2 metres / sec, which is a standard rate of movement used in many previous studies of VE exploration.

<u>Figure 5.3: the step-exercise machine used to simulate walking</u>

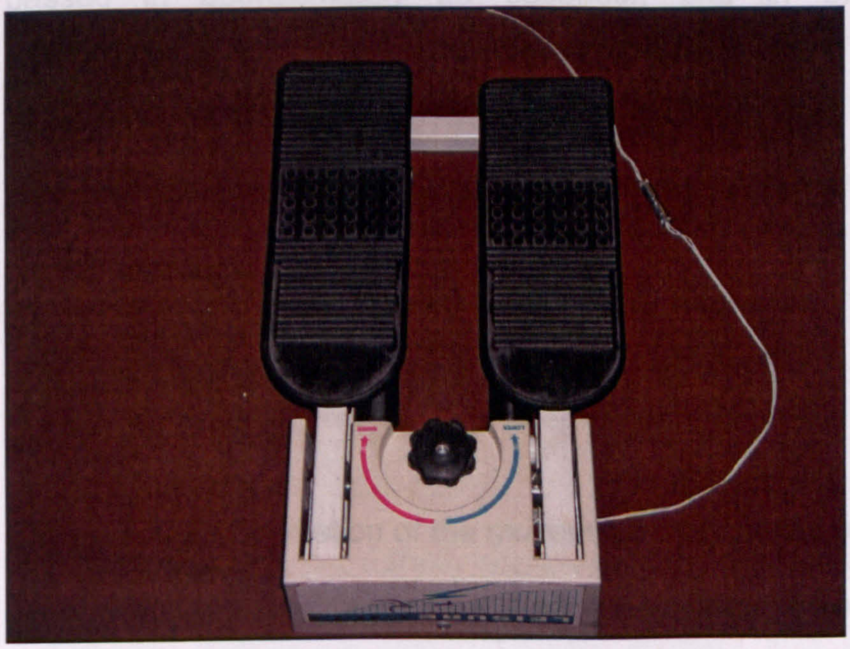


Figure 5.3, above shows the exercise machine that was interfaced with the VE and used by participants to simulate walking along the corridor.

Procedure

Participants were taken in pairs to a laboratory where they were introduced to the relevant apparatus. All participants were given the same non-specific instructions: that they would move along a corridor and they had to pay attention to objects in the corridor so that they could later answer questions about the corridor and objects. The A-W participants were given a few minutes to familiarise themselves with the stepping device. Familiarity with keyboard keys (single key operation) was such that no specific familiarisation was deemed necessary, and all A-F participants were able to make the necessary forward displacement without difficulty. Participants progressed smoothly through the corridor and past the final object without stopping and without any apparent difficulty. The active participants were asked to stop when they had passed the third object (i.e., when the third object had disappeared from view on the display). In the A-F condition, the objects in the corridor were typically passed in approximately 20 seconds., and in the A-W condition in approximately 30 seconds.

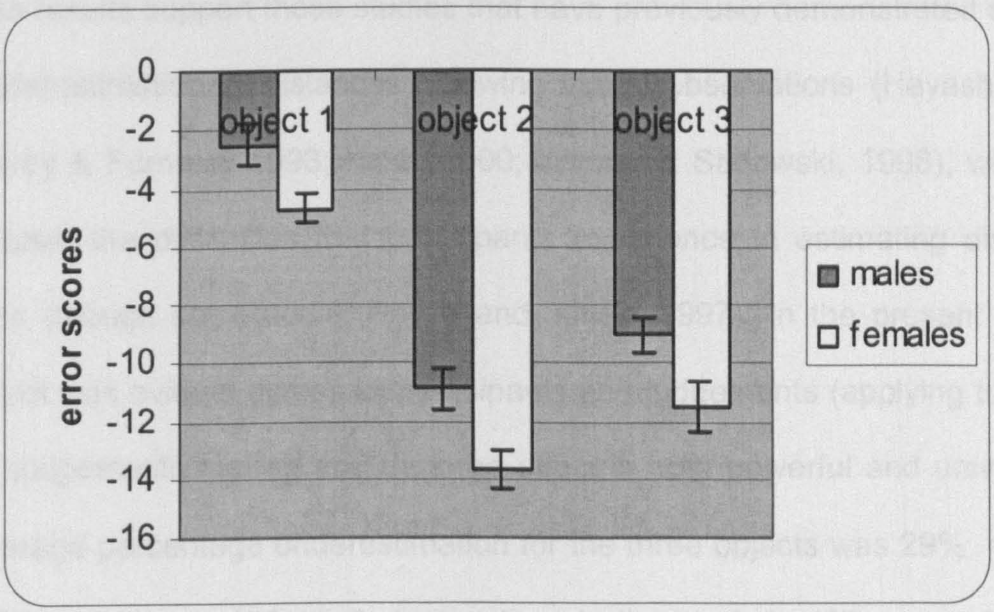
P-W and P-F participants stood close to their yoked active participant and viewed the projection screen. No verbal interaction was allowed between participant pairs.

Following the observation of the movement through the corridor, the participants were given a brief distractor task (counting back in 3's from 100) for one minute. They were asked to describe the objects in the corridor and their colours, to check that these were correctly remembered. They were then taken individually from the laboratory some 10m to a corridor for testing. The order in which active and passive participants were tested was alternated for successively tested pairs in each condition. In the test corridor, which measured 60m, was a white tape starting line at the near end of the corridor, across the width of the corridor (and similar to the starting line depicted in the virtual corridor). Starting at this point, the participant was asked to go along the corridor and indicate the positions of the 3 objects seen in the VE. Their distance estimations were measured from a white tape-line that was laid along the full length of the corridor, marked off in 0.5m intervals. Note that participants could not have used a strategy such as "counting steps" (A-W), or remembering "time elapsed" while moving in the VE (c.f., Kline, 2000), since they were tested on a single trial and during movement in the VE were unaware of the nature of the distance estimation task that they would subsequently have to perform.

RESULTS

Distance judgements were underestimates in 97.5% of cases. Across all conditions, comparison of the mean error with a theoretical mean of zero indicating a highly significant underestimation effect, $t(39)=18.69$; $p<.001$; this is also clear for each object from Figure 1, shown for each of the 4 experimental conditions. The percentage underestimation ([distance indicated in the real corridor/scaled distance in the VE] x 100%) for objects 1, 2 and 3 was 29.3%, 40.3% and 28.0% respectively. Differences between objects were found to be statistically significant, $F(2,64)=182.2$; $p<.001$, and pairwise comparisons revealed that all 3 objects differed significantly from one another, all p's<.001. The largest errors were recorded for the middle distance object. This rankorder profile of underestimates (object 1: -3.57, object 2: -12.29, object 3: -10.25) was repeated in both male (-2.5, -10.9, -9.0) and female (-4.7, -13.7 and -11.5) groups.

Figure 5.4: underestimation error scores for object by gender



As can be seen from figure 5.4 above, both male and female participants underestimated object distances in a similar pattern with the greatest under estimations being made for object 2. However, overall the underestimates of females were significantly greater than those of males.

The active-passive variable was not significant, F(1,32)=.198; p>.05, nor was the mode of movement variable, F(1,32)=.168; p>.05. However, a highly significant effect of gender emerged, F(1,32)=8.12; p<.009, reflecting the superiority of males over females (see Figure 5.4). This applied across conditions and objects, since the gender x object, gender x mode of movement, and gender x activity-passivity interactions were all non-significant, F's(1,32)=.061, .48, and .29 respectively; all p's>.05. All interactions with objects, and higher order interactions, failed to reach significance.

DISCUSSION

The results support those studies that have previously demonstrated substantial underestimation of distances following virtual observations (Hayashibe, 2002; Henry & Furness, 1993; Kline, 2000; Witmer & Sadowski, 1998), which might explain the difficulties that participants experience in estimating distances in VEs (though see Ruddle, Payne and Jones, 1997). In the present study, the effect was evident across all participants and judgements (applying to 97.5% of all judgements made), and thus the effect is both powerful and universal. The average percentage underestimation for the three objects was 29%, 40.3% and 28%, and thus substantially higher than in the study by Witmer and Sadowski (1998), who reported 15% underestimates after virtual viewing.

The comparisons among objects revealed that while the smallest underestimates were made for the closest object (the first to be encountered in the virtual environment), size of underestimation did not increase with object distance, but peaked for the intermediately placed object, and then fell. Clearly, this might reflect a tendency on the part of participants to assume that objects were equally spaced in the corridor (or at least, that the distances between objects 1 and 2, and 2 and 3 were more equal than they were). Whether this ordering effect would be reflected in tasks involving more or fewer objects or the longer distances used in some conditions by Kline (2000), is worthy of examination.

The present task was implicit, insofar as participants were unaware of the task which they would need to perform after virtual observation was completed. This design allowed three distance judgements to be made by participants in the context of a single trial, and it also eliminated some strategies that might have been adopted had successive virtual observation trials been used; for example, greater accuracy might have been achieved artificially were participants to have counted the number of steps taken to each object from the starting point, or otherwise used the time elapsed between the start of the displacement and the arrival at a particular target rather than judging distance per se (c.f., Kline, 2000). The inclusion of a distractor task was intended to discourage such behaviours, and the absence of doors and windows in the virtual corridor, while detracting from the realism of the simulation, prevented the tagging of targets to specific landmarks.

The substantial gender difference seen here was somewhat unexpected, in view of the simplicity of the basic task. Gender differences reliably occur when tasks involve objects to be mentally manipulated and rotated (Linn and Peterson, 1990; Voyer, Voyer and Bryden, 1995). However, a very substantial male superiority in gathering spatial knowledge from VE exploration has been previously reported by Astur et al (1998), and the present data appear to reinforce their conclusion. This raises the possibility that males and females make differential use of VE-based information, as a result of using different spatial strategies. On the other hand, such effects may be due more to differential computer use and familiarity among males than females. After testing large samples of males and females on a variety of spatial tests, including VE-based tests, Waller (2000) concluded that the contribution of gender per se to VE spatial knowledge acquisition is not substantial, especially when the effect of differential computer usage is factored out.

At first sight, the absence of active-passive and movement mode effects is perhaps surprising, insofar as the active control of forward movement, and cognitive factors influenced by preparedness to move (Rosebrock and Vamplew, 1999) might have been expected to have a significant effect on scores in a task of this kind. However, in neither case did the results approach significance. Thus the present study joins a long list of others in which passivity in VEs does not seem to have a detrimental effect on the acquisition of spatial information (Sandamas and Foreman, 2004; see Wilson, 1997), including the acquisition of distance information from expanding or contracting motion (Ito & Matsunaga, 1990). The absence of an active-passive difference is consistent with the results of Hayashibe (2002) who found greater distance underestimates in both active virtual exploration and passive video-recording observation conditions, compared with real world estimations.

The absence of an effect of mode of interactivity is arguably inconsistent with the findings of Werkohoven and Passenier (1999) and Chance, Gaunet, Beall and Loomis (1998) whose studies indicated that input devices providing proprioceptive feedback lead to better spatial knowledge acquisition. However, as mentioned above both of these studies focused on orientation rather than distance estimates to evaluate spatial learning. The current findings did, however, support those of Kline (2000) who demonstrated that proprioceptive feedback during VE exploration, while enhancing subjective feelings of movement, did not reduce distance underestimates. They could also be said to support those of Wilkie and Wann (2005) who found evidence to suggest that visual information maintains steering direction in a VE even when participants experience contrary vestibular information.

These variable results support the observation of Wilson and Peruch (2002) that different measures will result in diverse outcomes either because they reflect different aspects of spatial cognition or because they vary in sensitivity and that this factor is critical in terms of investigating active / passive differences. However, it is still surprising that the reafferent feedback, supposedly provided by the gait driven input device did not facilitate superior distance estimation, this perhaps indicating that in VEs the visual modality is predominant for spatial learning to a greater extent than it is in real space. Sandamas and Foreman (2004) suggest that the style of presentation may account for the lack of significant effects between active and passive participants found by most studies using VEs. That is to say, since the televisual medium is one through which we frequently obtain information of a spatial nature it is possible that humans have become adept at acquiring spatial information from 2-D depictions without the need for physically active interaction.

The yoked control paradigm used in this study has been criticised by Peruch and Gaunet (1990), who argued that active-passive differences might become masked if passives' performance varies according to the competence of the active with whom each happens to be yoked. However, this is unlikely to apply in the present situation, given the simplicity of the basic task that did not require extensive or strategic exploration.

The lack of any significant difference between active and passive participants perhaps suggests that whatever factors lead to distance underestimates in VEs apply equally to these groups. In this and in other VE studies using non-patterned rendering of environmental surfaces such as walls, participants may experience less visual expansion, optic flow and gradient information to the left and right of fixation point, as symmetrical visual expansion occurs during straight-ahead forward displacements (Gibson, 1966; 1979). Moreover, in the case of a VE displayed on a screen or monitor, the expansion takes place in more central regions of the visual field compared with natural viewing conditions. Since optic flow information is known to be used in computations of distance travelled (Gibson, 1966; 1979), any reduction in the quality of this flow might be expected to produce distance underestimation. However, the deficiency is equally applicable to active and passive participants, who are viewing the same screen display (c.f., Ito & Matsunaga, 1990). It remains to be determined whether particular forms of rendering might diminish the VE distance underestimation effect and thus improve the potential for VEs as spatial training media where distance estimation is an important consideration.

Chapter 6

Experiment 4.

To what extent do concurrent tasks affect spatial learning of simple VEs?

INTRODUCTION

Studies of human memory and spatial cognition have benefited from the use of virtual environments (VEs) (Gamberini, 2000), for example where real world exploration is limited by practical circumstances or where the manipulation of experimental variables is impossible given the constraints of the real world (e.g. Foreman, Wilson, Stanton, Duffy and Parnell, 2005; Peruch and Gaunet, 1998; Stanton, Wilson and Foreman, 2003; Wilson, 1997; Wilson and Peruch, 2002; see Rose and Foreman [1999] and Wilson [1997] for reviews). Environments used to train and assess aspects of memory have ranged from single rooms containing a few objects in an otherwise empty space (Sandamas and Foreman, 2003; Wilson, 1998), to more complex environments, such as homes, schools, hospitals, office blocks and shopping malls (Brooks, Attree, Rose, Clifford and Leadbetter, 1999; Foreman, Stanton, Wilson and Duffy, 2003; Foreman et al, 2005; Ruddle, Payne and Jones, 1997) to a part of a city (Maguire, Burgess, Donnett, Frackowiak, Frith and O'Keefe, 1998).

Many studies have suggested that learning in a VE results in the acquisition of representations of that space that are (at least, functionally) similar or equivalent to those acquired from real-world exploratory experience (e.g. Foreman et al, 2003, 2005; McComas, Dulberg and Latter, 2002; Witmer, Bailey, Knerr and Parsons, 1996; see Wilson and Peruch, 2002). However, there is controversy over the degree to which virtual and real environmental exploration is affected by the active or passive status of participants. The common finding in real world studies, albeit usually with larger scale spaces (Sandamas, 2005), is that active engagement confers better spatial learning.

Virtual exploration, however, does not appear to be affected by the active or passive status of the participant. In a recent study, Wilson and Peruch (2002, experiment 1) participants either actively explored a virtual environment, or passively observed an active participant's exploration, and then attempted to remember the locations of four targets. Surprisingly, subsequent orientation and way-finding measures found more accurate judgements for passive observers than active ones. In a second experiment, in a within-subject design, Wilson and Peruch found no difference between active and passive participants, and in a third, instruction to attend to environmental objects resulted in better recognition scores, while instructions to attend to the spatial layout resulted in better free-hand drawn maps. At least it must be concluded that active-passive differences are less reliable or predictable when VEs are explored, compared with real world environments. Indeed, advantages are sometimes reported for passive observers who watch the exploratory displacements of an active participant (Arthur, 1996; Sandamas and Foreman, 2004; Wilson and Peruch, 2002).

The research presented previously within this thesis has also demonstrated the fragility / inconsistency of active-passive differences in spatial learning of VEs. In Experiment 1 participants in the passive condition learned more about the spatial layout of the experimental VE than did those in the active condition. It was hypothesised that a contributory factor to this finding was that the spatial learning of active participants was impaired by the concurrent task of using the input device to navigate the VE. That is to say the working memory of active participants was excessively loaded. This issue was addressed in Experiment 3 by giving participants extended training in the use of the input device to navigate the virtual space. Theoretically it was hypothesised that this would reduce the cognitive effort required for navigation of the experimental VE and leave more working memory resources for learning its spatial layout. The findings of Experiment 3 supported the experimental hypothesis and active participants learned more about the spatial layout of the experimental VE than did their passive counterparts.

Experiment 4 considered the problem of concurrent navigation tasks interfering with spatial learning from a different perspective. Instead of providing extra training in the use of the input device (a joystick) an input device allowing active participants to move through the experimental VE by performing a walking movement was used. It was hypothesised that this more naturalistic interface with the computer would not only be beneficial for distance estimations (an aspect of spatial learning) by reducing the cognitive load on active participants, but also by increasing the motoric effort required by them to navigate the VE. However, due possibly to methodological constraints imposed by the computer hardware, the experimental hypothesis was not supported and participants in the active condition did not demonstrate any superiority over their passive counterparts in terms of estimating the distances between objects.

The current experiment also examines the idea that active participants may be disadvantaged in terms of their ability to learn the layout of a VE, if they must cope with the added task of interfacing with the computer. The displacements that are typically executed by an active participant when exploring a VE (moving a mouse or joystick forward, back, left or right, or depressing several keyboard keys creating the equivalent directional movements) are similar to those which have been used to disrupt visual-spatial functions in working spatial memory (WSM) tasks (Moar, 1978; see Logie, 1995). Thus, a way of examining the impact of input device operation on spatial virtual learning is to load groups of passive participants with various concurrent tasks that make differing demands on WSM. The dual-task approach is the most commonly used paradigm for gauging resource demands on working memory (Guttentag, 1989) and has consistently indicated that as the demands of concurrent tasks increase, performance on a central task diminishes (see Introduction of Experiment 2 for a more detailed review of working memory studies).

The WM model of Baddeley is based on the notion of a multi-component system (Baddeley, 1986, 1990, 2003) which includes a visual-spatial sketchpad that briefly holds visual-spatial information and is assumed to be responsible for setting up and manipulating visual-spatial images. The latter can be selectively disrupted by asking participants to perform spatial-motor tasks while remembering visual-spatial material. In one study, participants had to simultaneously perform a pursuit rotor task and either a verbal task or an imagery task. Pursuit tracking was found to seriously disrupt the imagery task, but not its verbal equivalent (Baddeley, 2003). Subsequent studies showed that other concurrent spatial tasks have a similar effect on the suppression of visual-spatial imagery (Baddeley, 1990). For example, requiring participants to press the keys of a pocket calculator located out of sight in a systematic spatial sequence is sufficient to disrupt visual-spatial imagery (Moar, 1978).

The present study was conducted to determine whether the visual-spatial working memory loading of a secondary task could influence spatial memory acquisition in a small room VE, in terms of object position recall. All participants in this study observed the same virtual spatial displacements, via the use of a pre-recorded standard exploratory sequence. It was hypothesised that if there is a reduction in spatial WM capacity due to the execution of a demanding secondary spatial task, participants will learn less about the environment from observing the exploratory sequence, the more spatially demanding the concurrent task is. Where the secondary task is non-spatial, or not spatially demanding (a simple repetitive spatial task, or a semantic task), spatial learning will be unaffected. Thus, it was hypothesised that the error score in placing objects on a map of the explored environment will be greater following spatially demanding tasks (i.e. keyboard shadowing of screen displacements, and complex spatial card-sorting) than following less or non-spatially demanding tasks (simple card-turning, or memory for a word list) or than error scores of controls who perform no secondary task.

METHOD

Participants

Sixty undergraduate participants, aged between 18 and 34 years, were recruited from the undergraduate population and awarded course credits for participation. They were divided into 5 groups of 12, each group having 8 females and 4 males. All had normal or corrected-to-normal vision.

Apparatus and Procedure

Recording the exploratory route

A pre-recorded videotaped exploratory route was used, representing an actual exploration made by a confederate participant prior to the start of the experiment. The virtual room was constructed to represent an actual room in the Psychology building of Middlesex University, though this was used as a laboratory and was thus unfamiliar to participants. The room measured 7 x 5 metres, and was modelled using SuperScape VRT 3.0 construction software. The environment was displayed, for the purposes of recording the exploration route, on a 21-inch monitor. The room was devoid of objects such as tables or chairs. Three walls were lilac in colour, one having cupboards and tall grey filing cabinets mounted flush to the wall. The fourth wall consisted mainly of windows with light-excluding curtains across them. The room had 6 objects located at floor level, randomly distributed but always remaining in the same position (Figure 6.1), these were a flower in a pot, computer monitor, bottle, road cone, triangular road sign, and a box. The floor was orange in colour. The confederate was allowed to move freely about the environment, using four keyboard keys to direct their displacements (forward, back, left rotate, right rotate), and was requested to visit each of the floor-level objects twice, but in an unsystematic way. A visit was defined as moving close to an object, and clicking on it using a mouse key. The entire exploration lasted 140 sec. The route was recorded on standard VHS video.

Figure 6.1: the virtual room

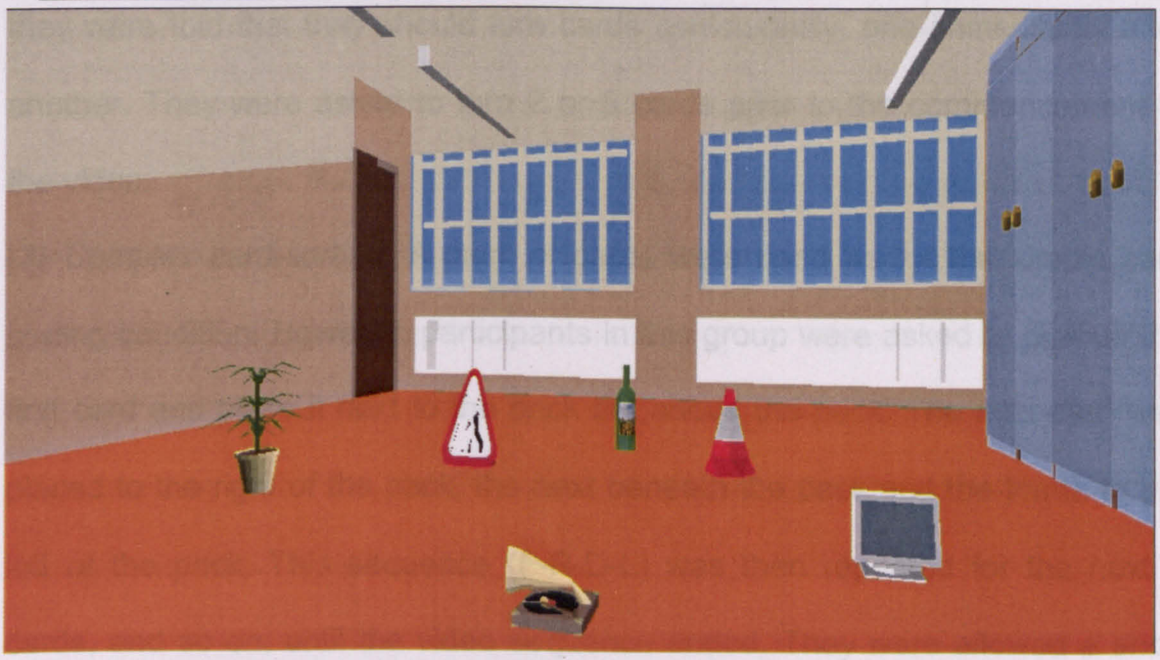


Figure 6.1 above, shows a screen shot of the virtual room and the positions of the 6 objects located on the floor. Only the road cone was present on the testing sheet.

Testing groups of participants

The same pre-recorded route (see above) was observed once by each of the experimental participants, displayed on a 26-inch colour video monitor. While the exploration was being observed, participants in the 5 groups engaged in different activities, as follows:

(1) Controls: These participants watched the video screen with no additional task.

(2) Simple card-sorting: Participants stood near a pack of playing cards and were asked to pick up each card in turn, turn it over, and place it face down next to the original pack. Participants were free to do this at a convenient speed but they were told that they should turn cards continuously, one immediately after another. They were asked to turn 2 or 3 cards prior to the commencement of the video.

(3) Complex card-sorting: A pack of cards were used as for the simple card sorting condition. However, participants in this group were asked to pick up the first card and place it next to the pack but above the pack. The next card was placed to the right of the pack, the next beneath the pack and the fourth to the left of the pack. This sequence (F-R-D-L) was then repeated for the next 4 cards, and so on, until the video sequence ended. They were allowed a short practice session prior to the commencement of the video.

(4) Verbal memory task: Participants were given a list of 6 concrete nouns to learn prior to the commencement of the video. They were asked to repeat the word list silently to themselves while watching the screen, throughout the video exploratory sequence. Following spatial testing, they were asked to recall the word list. In all cases they did this without error. This was taken to indicate that rehearsal of the word list had taken place during the spatial learning task.

(5) Keyboard shadowing: This condition was included to mimic the range and types of movement typically made by a participant as they explore a virtual environment. Participants were asked to take account of the direction of movement of the screen viewpoint and to depress appropriate keyboard keys (F, B, L or R) according to the direction of movement observed. They were

allowed to become familiar with the keys, and to depress keys while verbalising directions, for a short time prior to the commencement of the video.

Assessing spatial memory

At the end of the video sequence, each participant was taken to a table several metres from the video screen, and given a sheet of paper on which was depicted a screen down-load of the layout of the room. Colours were authentic, exactly as those in the VE. Only one of the floor objects was depicted (a road cone). Participants were asked to indicate, by drawing 5 crosses, the positions of the remaining floor objects, and to label each cross with the name of the object. They were given unlimited time, though almost all completed the exercise within 1-2 minutes. They then left the room and were debriefed as to the purpose of the experiment.

RESULTS

Performance was assessed using an acetate overlay, which depicted all of the 6 floor objects, and from which could be measured the distance of the centres of the 5 "missing" objects to the centres of the corresponding crosses which the participant had used to indicate their locations. Thus 5 error distances were obtained for each participant. (Where an object was not recalled, the participant was reminded of the identity of the object; they had to guess its location). Figure 2 shows the mean error score for each group.

Mean error scores for each object per participant were entered into a three-way, mixed 5x2x5 Groups x Gender x Objects Analysis of Variance (ANOVA) with objects a repeated measure. There was no gender difference, $F(1,50) = .46$; $p>.05$ nor any group x gender effect, $F(4,50) = .17$; $p>.05$. However, groups differed significantly, $F(4,55) = 5.29$; $p<.001$. Post hoc comparisons using the least significant difference (LSD) test showed that both the complex card-sorting condition ($p = .014$) and the keyboard shadowing condition ($p = .012$) were significantly worse than controls, while the verbal memory condition did not differ significantly from the control group ($p = .35$). The simple card-sorting condition was intermediately placed, not differing significantly from controls ($p = .47$) but also failing to reach statistically significant difference from either the complex card sorting or the keyboard shadowing groups (p's = .074 and .064 respectively). The verbal learning group produced arithmetically more accurate scores than any other, and showed highly significant differences from the complex card sorting and keyboard shadowing conditions (p's < .001), although there was no significant difference between this group and either the controls who performed no secondary task nor the simple card sorting group (p's = .35 and .103 respectively).

<u>Figure 6.2: mean error scores of participants in the control group and the four experimental groups.</u>

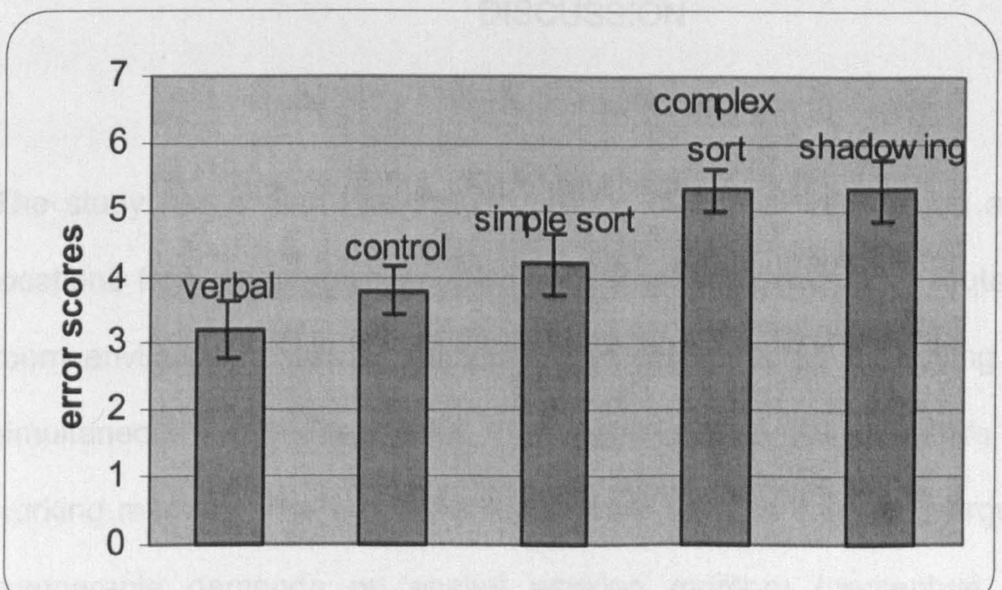


Figure 6.2, above illustrates that both complex card sorting and keyboard shadowing tasks caused participants to make the most errors in object placement.

There were no significant differences among the 5 objects used to test spatial location memory, $F(4, 200) = 1.49$; $p > .05$. Objects were apparently equally difficult to remember and locate. There was a significant positive correlation between scores on the 2 objects (bottle, and computer screen) most closely adjacent to the remaining reference object, the road cone, Pearson's $r = .355$; $p < .01$. There was also, however, a positive correlation between scores on the bottle and a more distant object, the plant, $r = .343$, $p < .01$, and thus performance in relation to particular environmental objects may be related to their prominence with respect to the reference object, but may also reflect some other stimulus quality such as salience or novelty. Other correlations among objects were non-significant.

DISCUSSION

The study has shown that the acquisition of spatial information about object locations from passive observation of a standard exploratory route in a small room environment was significantly adversely affected by having to perform simultaneous secondary tasks that made substantial demands on spatial working memory. The two tasks which were used in this study arguably made comparable demands on spatial working memory (perceptual and motor components) to those typically used to disrupt spatial working memory in previous cognitive experiments. In one case, the task exactly mirrored the movements needed to control exploration, since it required participants to shadow the displacements made during the observed exploratory sequence. Complex card sorting required working spatial memory for successive directions of turning. Although we have no data on the accuracy with which these tasks were performed, observation suggested that participants did perform competently. However, simple repetitive motor movements (required for turning cards monotonously) had no clear effect, failing to differ significantly from controls, and just missing significance by comparison with the two complex working spatial memory tasks, demonstrating that motor movement alone was insufficient to substantially disrupt spatial memory for virtual room objects.

The pattern of results strongly suggests that in VE-based training and testing, active participants may be prevented from taking advantage of their active status, by virtue of having to use spatial working memory capacity in the control of an input device. As mentioned above this was hypothesised from the findings of Experiment 1 in which untrained active participants who were operating a joystick to explore a VE for the first time were worse than their passive counterparts in an object placement task. This position is further supported by the findings of Experiment 2 in which trained active participants demonstrated the conventional active superiority seen in the majority of real-world studies. In the latter case, training reduced the cognitive load resulting from use of the input device so that spatial WM could be fully devoted to the acquisition of spatial information.

The present data are of interest in relation to previous studies in which children with disabling conditions were able to find their way around school buildings after a period of virtual exploration (Foreman et al, 2003). In some cases, children unable to operate an input device were trained by having them observe the displacements of an active explorer, who took instructions but operated the input device on their behalf. Far from disadvantaging the disabled children, it is likely that they were allowed more cognitive capacity to apply to the learning of the environment and would have been disadvantaged by having to operate an unfamiliar input device. This clearly has wider training implications.

Further, in the present study, simple distraction via a spatially undemanding secondary task (learning a list of words) did not have a disruptive effect. Indeed, the verbal learning group performed the spatial task with great efficiency. This excludes the possibility that simple distraction might have accounted for the deficit seen in the other tasks that did disrupt performance. It also reinforces the view that the cognitive process being disturbed by the complex spatial-motor tasks is spatial working memory, since in cognitive studies of working memory, it has been frequently shown that the components of WM are dissociable. In particular, a spatial task with a high cognitive loading will typically disrupt another spatial task but not a verbal-semantic task, and vice-versa. Miller et al (1991) found that spatial object sorting reduced finger-tapping rate, although Guttentag (1984) found that simultaneously learning a word list reduced finger-tapping rate, indicating that a verbal secondary task can negatively influence performance on a spatial task. The verbal task used in this study was particularly easy as participants merely had to maintain a previously learned word list using a sub vocal rehearsal and may not have had a substantial influence, for that reason. Simple card-turning in the present study appears to have had a small effect, since those participants' data were intermediately placed between those of controls and groups performing the more demanding psychomotor tasks.

The result poses questions regarding the degree of spatial-motor disruption that occurs in the performance of familiar real world tasks, where an active advantage over passive exploratory experience is usually obtained. For example, the motor movements made in controlling a motor vehicle (depressing pedals, steering, and operating gears) might also be expected to disrupt spatial learning, yet anecdotally (see Hart and Berzok, 1982), drivers typically obtain more spatial information than a passive passenger. It is likely that in well-trained motor tasks, the impact of spatial-motor movements is reduced. Driving becomes an automatic behaviour, except when conscious attention is required to modify a sub-program, as when traffic suddenly slows and a driver has to react. It is likely that at moments when such distractions occur, spatial information cannot be processed. Likewise, a novice driver is unlikely to acquire as much spatial information after driving a route in an unfamiliar town as an experienced motorist.

Other contributory factors, such as the attention directed toward spatial aspects of the task, may be significant (Wilson and Peruch, 2003). Using the car driver-passenger example again, a passenger who is passively gazing out of the vehicle window is likely to obtain less spatial information than one that is navigating with a map and/or directing the driver. In the latter case, the active passenger may acquire more information than the cognitively passive driver may. The example points out the importance of distinguishing simple motoric activity from engagement in the task in hand. In many cases a vehicle driver is active in both respects and the passenger passive in both respects. Further studies are required to determine whether the spatial information acquired by drivers and passengers can be manipulated according to attentional instructions, driving familiarity, or via the imposition of secondary tasks.

In summary the findings here support the hypothesis generated by the findings of Experiment 1, and further supported by the findings of Experiment 2 that the untrained use of an input device to explore a VE can be detrimental for spatial learning of that VE. As has been demonstrated here, concurrent tasks designed to approximate this situation – the untrained use of an input device – in terms of visual-spatial working memory loading also have a negative impact on spatial learning. Logie (1995) proposed that the VSSP comprises separate spatial and visual sub-systems, whilst Pickering, Gathercole, Hall and Lloyd (2001) argued that the VSSP is fractionated into dynamic and static sub-systems. The methodology of the current study has not been designed to examine these issues which are, according to Hitch (2005), highly complex and controversial, and dissociation between possible VSSP sub systems is not possible from the findings here. However, it is worth noting that whilst the present findings are couched in terms of general visuo-spatial scratchpad loading, at this stage there also remains the possibility that the Central Executive is implicated. Further research outlined in the final discussion below will enable the further clarification of this situation.

Chapter 7

Experiment 5.

Active and passive spatial learning from a desktop VE in male and female participants: a comparison with guessing controls

INTRODUCTION

The effective use of VEs in spatial training with active participants (McComas et al, 1998; Ruddle et al, 1997; Stanton et al, 1996) suggests that actives acquire high quality spatial information, and by implication, that passives are likely to do so as well. In past studies, however, where no difference has been observed between participants who have either actively explored, or passively witnessed exploration of a virtual environment (VE), this could be because they are equally good at remembering the spatial layout of a VE or equally bad. Even when differences are found such as in Experiments 1 and 2, here, combined placement error scores can appear to be high. For example, in Experiment 1 in which participants had to place 8 objects on a 1.8x1.6m floor plan subdivided into 4 quadrants of equal size, combined placement error scores ranged from 128cms – 528cms. In Experiment 2, where participants had to place 8 objects on a 0.8mx0.7m floor plan, again subdivided into four quadrants, combined placement error scores ranged from 78cms – 188cms. Participants in these studies did, however clearly demonstrate that spatial learning had taken place as they improved significantly across trials under all conditions, but the question remained as to how good that spatial learning was. The main purpose of the present study was therefore to assess the performance of both active and passive groups against that of a naïve control group, who could only make guesses about the spatial layout of the environment. Using a spatial task similar to that utilised in Experiments 1 and 2 the aim of the current experiment is to demonstrate that the spatial knowledge acquisition in VEs is substantial for both active and passive participants as this has not been formally investigated to date. The hypothesis predicts that both active and passive participant groups will make more accurate judgements than the guessing control group.

Gender differences in spatial performance are frequently reported, favouring males (Linn and Petersen, 1985; Voyer, Voyer and Bryden, 1995), and although these are most often observed in relation to mental rotation (Geary, Gilger and Elliot-Miller, 1992), gender differences may also exist in larger-scale navigational abilities. Males have been reported to attend primarily to cardinal and distance attributes, while females attend more to landmarks when navigating or using maps (Choi and Silverman, 1996; Eals and Silverman, 1994). Moffat, Hampson and Hatzipantelis (1998) found that males showed superior maze learning in a VE, and indeed, Astur, Ortiz and Sutherland (1999) have suggested that gender differences are especially likely to appear in virtual spatial tasks in which a simulation of an arena is navigated and remembered. On the other hand, some studies (e.g., Waller, 2000) have shown that gender is a relatively minor factor in determining performance in such tasks, especially once the effects of computer game familiarity is factored out. To investigate possible gender differences in performance of the present task, both male and female participants were included.

METHOD

Participants

Participants were 24 male and 24 female undergraduate students. They were aged 17-30 years and all had normal or corrected-to-normal vision. Thirty-two participated in the study as experimental participants. These gave informed consent to participate in the study and were informed that they could withdraw from the study without penalty at any time. Their participation was rewarded with 'experimental participation' credits. The remaining 16 undertook a relatively trivial task (see Procedure) for which informed consent was considered unnecessary.

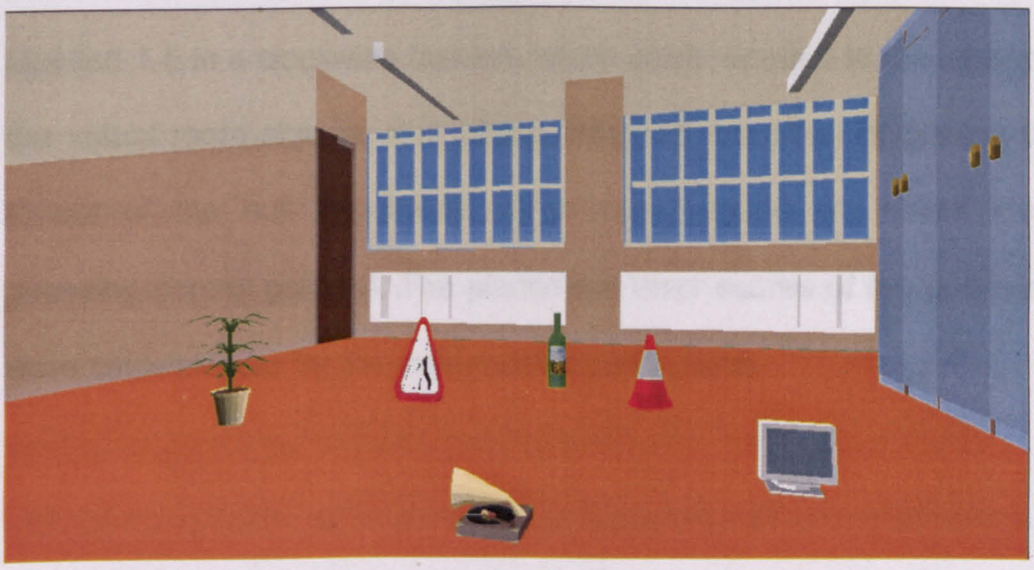
Equipment

The VE was created using Superscape VRT software, and displayed on a standard 21-inch monitor. The environment was dimensioned in a similar fashion to previous comparable studies (McComas et al, 1998; Stanton et al, 1996), with the virtual head height set to a typical human value of 170 cm.

Procedure

Testing took place in a quiet room, illuminated by overhead strip lights and with external light excluded by blinds. Thirty-two participants were tested in pairs. The pairs were given simultaneous instructions, which differed according to the group to which they had been allocated. Students were paired in same-sex pairings but otherwise randomly. In each pair, an active participant sat at a comfortable viewing distance from a desktop computer monitor on which was depicted a virtual environment (VE). The VE consisted of a room, which could be entered by opening a door via a mouse click. The walls were sand coloured and the floor grey, and the room had windows, doors and cabinets around the edge. Distributed within the room were 6 colourful objects (traffic cone, computer monitor, bottle, pot plant, gramophone, and roadwork sign), an object array which could be easily remembered. The objects were placed in a roughly circular arrangement as illustrated by Figure 7.1 below. The active participant was asked to explore the room for up to 5 minutes (until they reported familiarity with the depicted environment; cf. Waller, 2000), using the directional keys on the computer keyboard to move themselves about in virtual space. To ensure that they had experienced all the objects in the room, they were asked to visit each of them twice in the course of exploring. A visit to an object consisted of moving toward it as though to touch it, and registering the visit via a mouse click. Objects could be visited in any order, but participants were asked to vary the order in which visits were made on each tour. Passive participants sat beside their paired active participant and observed their exploration. The pairs did not communicate with one another. At the outset, all participants were given the instruction to "remember the layout of the room", and thus the task was an explicit task, although since the participants did not know exactly what was to be examined, there was an implicit element.

Figure 7.1: screen shot of the VE experienced by participants in all conditions



Following the exploration phase, the participants were taken without delay to different parts of the room, and tested individually. They were given a plain sheet of A4 paper on which was shown a map of the room containing one of the room objects (the traffic cone). They were asked to draw 5 crosses, representing the other objects and to label them. They were not restricted in time, but all participants performed this task within 1-2 minutes.

The maps were assessed for placement accuracy by measuring the distance in cm. of the true object position (taking the centre of the object as a reference) from the centre of the corresponding marked cross, drawn by the participant.

In order to compare the results with guessing controls, two further groups of participants were recruited, 8 males and 8 females, who were tested individually. They were given the room map (with only the traffic cone shown) and asked to guess where 5 objects might be placed in the room, and to indicate their guessed positions via crosses, numbered arbitrarily 1-5 (computer = 1, pot plant = 2 and so on). (In many cases, a circular arrangement of objects was anticipated by the guessing participant; objects were often placed and labelled 1-5 in a clockwise fashion, which corresponded to the labelling order of the virtual room objects. If anything, this had the effect of biasing the data in favour of the null hypothesis when comparisons are made involving the guessing control groups). The placement error scores of the guessing controls were calculated as for the experienced participants.

RESULTS

Initially, a 1-way independent analysis of variance (ANOVA) was used to compare the placement accuracy of the three groups (active, passive and guessing). The dependent variable was the mean error placement score (measured in cm.) averaged across the 5 objects. A highly significant group effect was obtained, $F(2, 45) = 17.2$; $p < .001$. There was no significant difference between the active and passive experienced participants, $p > .2$, and indeed, the passive participants' error scores were arithmetically lower than those of active participants (Figure 7.1) were. However, there were highly significant differences between both groups of experienced participants and guessing controls, both p's $< .001$.

The placement error scores of the 32 experienced participants were then examined using a 2 (activity) x 2 (gender) x 5 (objects), 3-way mixed analysis of variance (ANOVA) with object the repeated measure. The guessing participants were excluded from this analysis, since the inclusion of guessing data would have served only to obscure differences between male and female and active and passive groups, and among objects.

The analysis confirmed the absence of any significant difference between active and passive conditions, $F(1, 28) = 1.306$; $p > .05$, and revealed no significant difference between gender groups, $F(1, 28) = .064$; $p > .05$. There was no interaction between gender and activity, $F(1, 28) = .70$; $p > .05$. Objects differed in the memorability of their spatial locations, $F(4, 112) = 2.88$; $p < .03$, the gramophone being significantly more accurately placed than the road sign, $p < .02$, but there was no interaction between activity and object, $F(4, 112) = 1.07$; $p > .05$, nor between gender and object, $F(4, 112) = .60$; $p > .05$, and no significant 3-way interaction, $F(4, 112) = .64$; $p > .05$.

<u>Figure 7.2: mean error scores by condition</u>

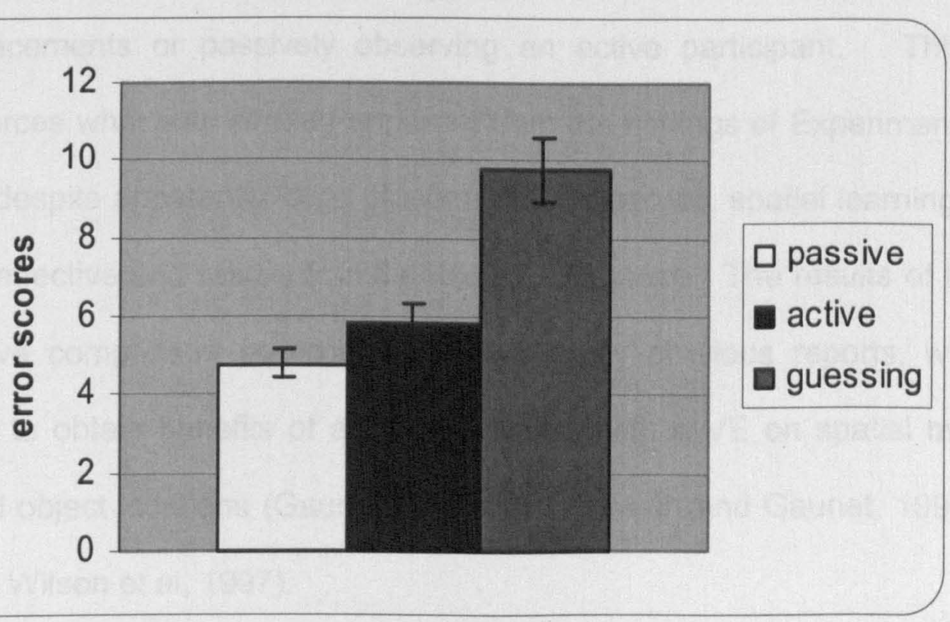


Figure 7.2, shows the mean placement errors in cm. averaged across the 5 placed objects in groups of participants who actively explored the VE (active),

passively watched while an active participant explored (passive), or who guessed the object positions without VE experience (guess).

DISCUSSION

It is clear that both active and passive exploration groups acquired a considerable amount of spatial information from their exploration of the VE, insofar as both groups were significantly more accurate in placing the room objects than the guessing control group. The absence of a significant difference between the active and passive groups implies that they achieve an equally *good* level of performance, and not an equally poor level. In other words, the failure to find differences between these groups is not due to a 'floor' effect. The placement errors of guessing controls were double those of experienced participants, whether the latter were actively directing and controlling their displacements or passively observing an active participant. This formally reinforces what was already apparent from the findings of Experiments 1 and 2 that, despite apparently large placement error scores, spatial learning in VEs is both effective and readily transferable to real space. The results of the active-passive comparison are consistent with many previous reports, which have failed to obtain benefits of active interfacing with a VE on spatial memory for virtual object locations (Gaunet et al, 2001; Peruch and Gaunet, 1998; Wilson, 1999; Wilson et al, 1997).

The reasons for the lack of significant effects between active and passive participants may relate to the style of presentation, since the televisual medium is one through which we frequently obtain information of a spatial nature and it is possible that humans are adept at acquiring spatial information while passively observing 2-D screen depictions. Against this view is that in one study in which activity in a VE was found to enhance spatial memory, Peruch, Vercher and Gauthier (1995) had passive participants watch a screen on which route displacements were shown. However, it is perhaps significant that in that case, the observers were alone and not shadowing an active explorer per se. It is also possible that routes (Peruch et al, 1995) and gross configurations (Brooks et al, 1999) can be more effectively learned by active explorers of VEs than the positions of objects in virtual space.

Alternatively, and perhaps more likely, the medium in which VR is presented may confer a disadvantage on the active participant. The movements that the active participant needs to make in order to displace themselves in virtual space are themselves spatial in nature (depressing particular keyboard keys or moving a joystick) and may compete for cognitive capacity. In particular, spatial working memory functions (Baddeley and Lieberman, 1980) can be particularly influenced by interference such as tapping in spatial sequences. A further factor is the incidental versus explicit nature of the task (cf. Attree, Brooks, Rose, Andrews, Leadbetter and Clifford, 1996), since it is arguably more likely that participants in VE studies will be explicitly aware of the nature of the knowledge that they are expected to acquire.

The absence of gender differences in performance in the current study argues against the assertion by Astur et al (1999), that VE tasks are especially effective in demonstrating gender effects in spatial cognition. Indeed, where males have been found to outperform females, the effect is typically small, and mainly attributable to differential familiarity with computers and computer games (Waller, 2000). Nevertheless, the nature and scale of the task might also be significant, since Eals and Silverman (1996) have argued that while males outperform females on larger-scale tasks, the reverse may be true for tasks involving landmark use in proximal space. Further studies, with larger participant groups, are required to examine these possibilities.

Chapter 8

Experiment 6.

The effects of active versus passive exploration and familiarity on the acquisition of spatial representations of a virtual urban space

INTRODUCTION

Modes of travel are of interest to researchers looking at the effect on spatial learning of active and passive navigation within environments because different transportation modes require the traveller to interact with the environment to varying degrees and appear to lead to differing levels of spatial understanding of those environments. A common comparison is that of car driver – perceived as being active within an environment - versus car or public transport passenger – perceived as being passive. For instance, Appleyard (1970) who was involved in the development and planning of an expanding city in Venezuela, asked hundreds of the city's inhabitants to draw sketch-maps of their local areas and the city as a whole. He found that inhabitants who drove around the city were able to produce much more accurate maps than those who travelled, in the main either by bus or taxi. Appleyard concluded that variations in travel mode "profoundly" influenced peoples' representations of their environment. Similarly, Hart and Berzok (1982) also argued that car drivers learn more about the spatial layout of environments than do car passengers, whilst studies with young adults have found evidence to suggest that those who drive are better able to draw maps of areas adjacent to their own neighbourhoods than are their peers who do not drive (Andrews, 1973; Brown and Broadway, 1981).

Transport passengers have also been found to be less knowledgeable concerning the geography and spatial layout of environments when compared to pedestrians. For example, Hart (1981) found that children who walked to school were more accurate at estimating the distance from home than children who rode to school, while Joshi, MacLean and Carter (1999) found that children who walked to school demonstrated a greater knowledge of their environment by including more landmarks in their drawings of their neighbourhoods than their peers who were driven.

However, despite their advantage over transport passengers, in terms of spatial learning, their range and lack of attention to environmental cues limit pedestrians, when compared to drivers. Beck and Wood (1976) in a review of the research literature contend that drivers display greater and more accurate knowledge of the layout of environments such as cities than both pedestrians and users of public "mass" transportation. This appear to be because, in addition to having greater mobility and travelling at "geographic scale", drivers must attend more vigilantly to features of the environment such as street names, road signs and potential landmarks, as well as distance and directional information. Additionally, drivers may also benefit, in terms of spatial learning, from being in control of actions whilst experiencing visual-motor interaction and making decisions concerning future actions (Gaunet, Vidal, Kemeny and Bethoz, 2001). This coincides with the ideas of Siegel and White (1975) who suggested that route learning involves a sequence of decisions and takes place through the paired associations of actions with landmarks ('stimulus-response pairing') and that the sensori-motor nature of this process is facilitated by activity.

In addition to activity, spatial knowledge of environments also appears to benefit from familiarity as demonstrated by the observations of Beck and Wood (1976) that, "*Long-term residents of environments make better maps, both in content and veridicality, than recent arrivals.*" Their conclusions were aptly illustrated by the findings of Ladd (1970), that when black urban adolescents drew maps of their neighbourhoods these increased in richness of detail as a function of both familiarity and activity. Similarly, Warner, Kaplan and Ciottone (1981) showed that children's representations of their local areas were more related to the length of time they had lived there than to their age. Further, Appleyard (1970) and Moore (1976) found that the accuracy of sketch-maps of cities drawn by city residents improved as a function of length of residence, and Appleyard (1970) found that with increased familiarity the use of spatial elements in sketch maps became more common, unlike sketch maps drawn by recent inhabitants that were overwhelmingly sequential in nature. On a smaller environmental scale Thorndyke and Hayes-Roth (1982) found that employees within a large building improved on distance and direction estimate measures as a function of experience within the building. This finding is further supported by Herman, Kail and Siegel (1979) who found that students' landmark, route and survey knowledge of their new campus improved significantly over a three-month period. Intuitively it seems true that the more time we spend in an environment the more we get to know its spatial layout, landmarks and other features. Numerous studies have confirmed the positive relationship between familiarity and the accuracy of people's mental representations of environments (O' Neill, 1992).

Herman et al (1979) proposed that 'cognitive maps' are the means by which organisms store internal representations of environmental layouts. Siegel and White (1975) proposed that cognitive maps are constructed through the acquisition of three types of hierarchical knowledge: landmark, route and survey. Firstly, Landmarks are encoded, mainly via the visual modality, and are the decision points in an environment around which spatial activity is organised. Siegel and White proposed that landmarks are the strategic foci [or hubs] that the person moves around, or travels to and from. Secondly, route knowledge develops - routes are the sensori-motor routines that connect landmarks to each other via habitual lines of movement and familiar lines of travel (Lynch, 1960). Traditionally routes are thought of as fairly rigid representations that are sequential in nature and not readily reversible, at least during the initial stages. However, with familiarity, knowledge of landmarks and routes crystallise into a map or survey type representation, a cognitive map. This is the final developmental stage in Siegel and White's (1975) model. It allows the individual to connect previously unconnected landmarks via routes not previously travelled and to be relatively free of reliance on any specific sequence of landmarks since the configuration of all landmarks is now understood and routes between landmarks are multi-dimensional and multi-directional. The more sophisticated the cognitive map the more integrated the route and landmark knowledge of the individual, giving them an advantage in terms of way-finding and the spatial organisation of their environment (Siegel and White, 1975).

The driver/passenger scenario as presented by Appleyard (1970), Hart and Berzok (1982) and others has often been referred to by subsequent researchers in the area as indicating the benefits of activity for spatial learning. Likewise familiarity with an environment is generally accepted as critical in leading to greater spatial knowledge, whilst the model proposed by Siegel and White (1975), described as the dominant framework (Montello 1998) for the development of spatial representations has provided a theoretical framework in which to couch spatial learning and has been the catalyst for much research in the area.

One purpose of the current study was to recreate the driver/passenger scenario using a complex virtual reality environment, in order to investigate the relative benefits and deficits of active and passive modes of exploration for spatial learning. Participants in driver/passenger pairs 'drove' around a complex virtual environment (VE) under three exposure conditions with participants in the 'driver's' seat controlling displacements through the VE. Gaunet, Vidal, Kemeny and Bertoz (2001) suggest that active exploration of a VE with an input device shares important features with real world active exploration such as the tight linkage between visual self-motion and motor activity. Aginsky, Harris, Rensink and Beusmans (1997) have also proposed that driving simulators offer the possibility to study relatively lifelike active navigation in a controlled environment. The recreation of the driver/passenger scenario in a VE would therefore appear to be a credible research approach to investigate differences in spatial learning between the two travel modes.

A second purpose of the current study was to explore the development of spatial knowledge as a function of increased experience within a VE, particularly in terms of the model proposed by Siegel and White (1975). It is generally accepted that the similarities in spatial information offered by and acquired from virtual and real environments is considerable (Peruch and Gaunet, 1998; Wilson, 1999) and therefore VR should offer an excellent medium in which to study the processes by which spatial knowledge develops.

Based on the idea that active movement through the environment leads to better spatial learning than passive movement and that drivers in the real world have demonstrated this advantage over passengers, one of the experimental hypotheses was that drivers would learn more about the spatial layout of the VE than passengers in terms of route and survey type knowledge. It was also hypothesised that their advantage would increase with length of exposure as their control of action, decisions about direction and displacements and visual-motor interaction opportunities (Gaunet et al, 2001) would increase with exposure, giving them an advantage over passengers who, being passive, do not benefit from these components.

However, it was also hypothesised that passengers' *memory for landmarks* encountered within the VE may be better than that of drivers. Memory for landmarks in terms of 'what' as opposed to 'where' is not necessarily spatial in nature and may not, therefore, be advantaged by activity. Montello (1998) describes landmarks as discrete units that, in themselves, do not contain spatial information. In addition to which the findings of Attree, Brooks, Rose, Andrews, Leadbetter and Clifford (1996), that passive participants recalled more objects encountered during VE exploration than did active participants, also support the hypothesis. Attree et al (1996) suggested that their findings could have been brought about because active participants must focus on navigating a VE, while passive participants can focus all their attention on memorising objects encountered within it.

Focus of attention has been identified as a possible confounding factor in research looking at the benefits of activity for spatial learning. Wilson, Foreman, Gillett and Stanton (1997) speculate that they found no active versus passive differences in spatial learning because participants knew that their spatial abilities would be tested post exploration of the experimental VE. Further, it has been suggested that passive participants may be able to compensate through careful and effortful attention to the spatial learning task, for their lack of navigational control thereby masking the beneficial effects of activity (Wilson, 1999). In an effort to mitigate the possible confound presented by direction of attention, participants in the current study were not informed of the nature of post exploration testing. The incidental rather than intentional nature of their spatial learning was thought to give a clearer indication of the influence of activity for spatial learning when compared to passivity.

As mentioned above familiarity with environments has been shown to facilitate the development of spatial representations of them. In addition to mode of travel participants also experienced the VE under three length of exposure conditions. It was hypothesised that, in line with previous research findings, spatial knowledge of the VE would develop as a function of time spent exploring it. Whilst no hypothesis was made, it was also of interest to see if there was any evidence to suggest that spatial learning followed the sequential – landmark, route, survey - pattern suggested by the model proposed by Siegel and White (1975).

METHOD

Participants

Fifty-four undergraduate psychology students attending a London University participated in self-selected pairs in exchange for course credits. There were 45 females and 9 males with a combined mean age of 23 years and a range of 18 to 43 years. Thirty-three (28 females and 5 males) were licensed car drivers and 17 (10 females and 7 males) considered themselves as regular computer gamers. All had normal or corrected to normal vision. All were randomly allocated to either the passenger (passive) or driver (active) conditions but self-selected for the exposure conditions dependent on how much credit they wished to gain. Five tours gained an hour's credit, 10 tours one and a half-hours credit, and 15 tours two hours credit.

Setting

The experiment was run in a large room (approximately, 7 m^2) lit by fluorescent lighting designated as the VR lab. The windows were blacked out to enhance the virtual image, with the lights switched off, and to increase the sense of immersion by reducing the conspicuousness of objects in the room whilst participants explored the VE. In addition to containing a computer, interface device and projector, as described below, the room also contained a number of desks and chairs to be used by participants when completing the outcome measures.

Apparatus

The VE was constructed using Superscape 3-D virtual reality software run on an IBM compatible desktop PC with an Intel Pentium 3 processor. The output image was fed directly to an Electrohome Projection Systems ECP 3500plus standard RGB projector. The 1 x 2 metres image was projected onto a 2 x 4 metre screen (painted onto a wall) 4.5 metres away from the projector and 1 metre above floor level. The image was projected over the heads of the participant pair who sat side by side at a desk, 3.5 metres from the screen. Participants in the Driver condition sat at the right-hand side of the desk with the input device in front of them and their passive counterparts to their left, replicating the layout of a right-hand drive vehicle. The input device was a ThrustMaster steering wheel and pedal arrangement providing directional, acceleration and braking control. The steering wheel was fixed to the desk with the pedal unit sitting on the floor underneath the desk.

The layout of the virtual environment was designed to resemble a generic small town centre consisting of six blocks containing buildings and trees bounded by roadways, four cross roads, a T-junction and a centrally located roundabout with 5 exits (see Figure 8.1 below). The virtual buildings were of several types including multi-storey office blocks, brick rendered residential type houses, shops, including a supermarket and fast-food outlet, a bank and a church. In addition to a roundabout, other street features included railings, a pelican crossing, a post-box, a phone-box (see Figure 8.3 below), two statues and a clock-monument. Many of the objects within the VE, such as the trees, street furniture and generic buildings, were taken directly from the Superscape warehouse, however buildings dressed in the liveries of Barclays Bank, Tesco, WH Smith and KFC were created for the current study. In essence the VE was designed to contain many of the elements and the complexities one would expect to find in a small town centre (See Figures 8.2 and 8.3 below).

Figure 8.1: a bird's eye view of VE road layout

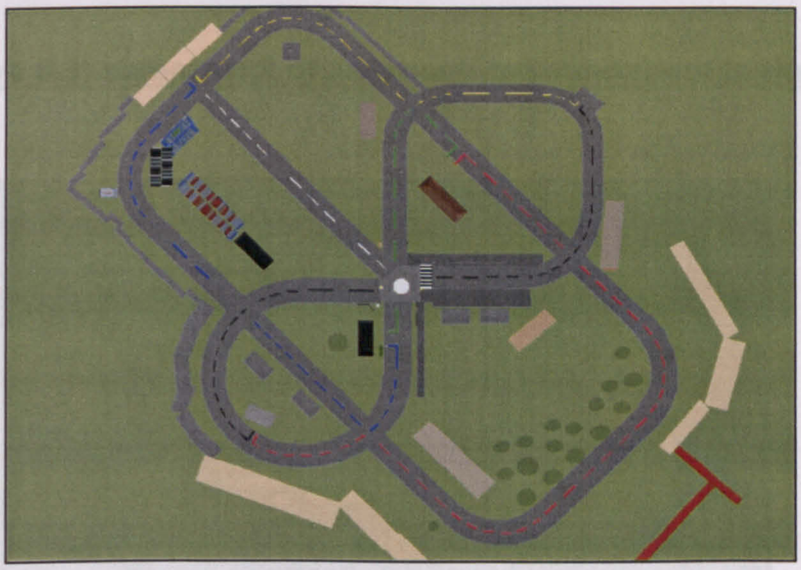
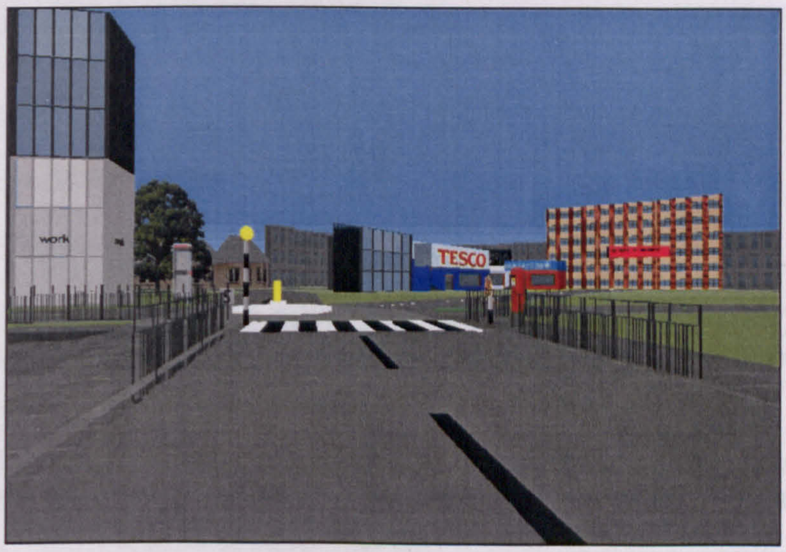


Figure 8.1 above, shows the road layout of the VE. The red, green, blue, yellow and black road markings indicate the routes that participants had to follow. The positions of buildings and trees are also shown.

Figure 8.2: screenshot of a junction in the VE

Figure 8.2 above, and Figure 8.3 below, illustrate the nature of the experimental VE. Both screenshots were taken from the same viewing height as would have been experienced by participants as the drove around the environment following the road markings that can be seen in these shots and in Figure 8.1.

<u>Figure 8.3: screenshot of approach to roundabout in the VE</u>



Figures 8.2 and 8.3 illustrate the range of buildings represented within the VE, the street furniture and the relative scale of the whole, conveying a small town feel. In terms of scale, the environment was designed so that all of the objects and features within it were sized appropriately relative to each other and the participants' viewpoint, which was set at a height to replicate that of people travelling through the environment by car. However, although the scaling was in many ways arbitrary and based on approximations, the overall look and feel of the VE was correct and conveyed what the author intended, a complex but naturalistic environment through which participants could drive. Whilst the colour of the road surfaces were grey, the predominant background colour of the ground was green. The ambient lighting conveyed a daytime scene and the predominant colour of the sky was blue.

Procedure

Participants entered the laboratory in pairs and were asked to complete the following short questionnaire:

Participant No: __________ Exposure: __________ Condition: ____________________

Age: ____________

Gender: ________________________________

Do you drive? _______

If yes how long? _____

Do you play computer games? _________

If yes approx. how many hours PW? ______________________________________

On a scale of 1 to 10 (1 being very slowly and 10 being very quickly) how would you rate your ability to learn your way around a new environment______________________

On a scale of 1 to 10 (1 being very poor and 10 being very good) how would you rate your navigation and way-finding skills in general? ___________________________________

After completing the questionnaire they were shown the experimental set-up as described above and told that they would be replicating a driver / passenger scenario and that after familiarisation with the input device they would be randomly allocated as either the driver (active condition) or passenger (passive condition). For familiarisation each participant in turn sat at the input device and after the controls were explained to them 'drove' for up to 5 minutes, or until they reported that they felt comfortable, around a virtual road circuit. After adjusting to the sensitivity of the controls in terms of turn and acceleration, all participants completed this task with ease. Participants were then randomly allocated, by the toss of a coin, to either the driver or passenger condition. After allocation they were directed to sit in the appropriate positions at the desk which acted as the car interior (see apparatus section for details). Once seated, the participants were told that the experiment was designed to recreate a driver passenger scenario in which they would be driving around a VR rendition of a small town centre. Participants in the Driver condition were instructed to follow road signs and markings to guide them on several routes taking them on a circuit around the VE, whilst participants in the Passenger condition were told only to attend to the screen. Since Passengers were required to sit and view the displacements of their Driver counterparts for anything between 20 and 60 minutes, depending on which exposure condition they were in, it was felt that it would be beneficial in terms of their attentional effort to remind them that their role in the study was also extremely important. The participants were not told that after they had experienced the VE they would be tested on their knowledge of the spatial layout of the VE and the objects within it.

In addition to verbal and demonstrative instructions participants were also given a copy of the following set of written instructions:

> You have just moved into a new town. Each day you must make five journeys. At the moment you have to follow the colour-coded and numbered road-markings to guide you:
> Journey 1= **red route**; journey 2 = green route; journey 3 = **blue route**; journey 4 = ; journey 5 = **black route**.
>
> You must complete each journey in order (1-5) using the numbers and colours to guide you. Each journey has a specific start and end point indicated by a road marking of the appropriate colour at right angles to the direction of the road. In other words the beginning and end markers are across your path rather than in the direction you are travelling.
> You will be asked to complete each journey a specified number of times. During the experiment it is important that you concentrate on the virtual environment and the task and do not talk to the participant with whom you are paired.
> If any of the above written instructions or if any given verbal instructions are unclear please do not hesitate to ask. Try to relax and hopefully you will find this a very stimulating and enjoyable experiment in which to participate.

Figure 8.4: the start point of route 1 and the terminal point of route 5 in front of the building labelled 'Home'

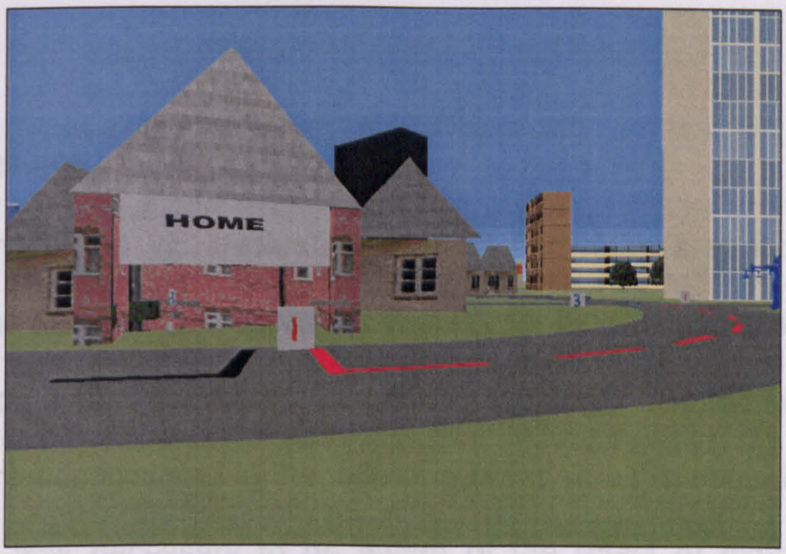


Figure 8.4 shows the point at which all participants began their travels around the VE. It also illustrates the start and terminal points of the first and final of the five routes that the participants were instructed to follow. The five routes started and terminated in front of five labelled buildings – Home > School >Work >College >Babysitter > Home > and so on – and took in all of the VE, crossing over each other at junctions but not doubling-up on each other, i.e. each route led participants along roads not previously or subsequently traversed when following another route (See Figure 8.1).

As mentioned above, participants had to follow the routes a set number of times depending on which exposure condition they were in. Participants that followed each of the routes 5 times - that is completed 5 tours of the VE - took on average just under 15 minutes to do so, equating to just under 3 minutes per tour. Participants that followed each of the routes 10 times – that is completed 10 tours of the VE – took on average 27.5 minutes to do so, equating to 2 minutes 42sec per tour. Participants that followed each of the routes 15 times took on average almost 51 minutes to do so, equating to almost 3.5 minutes per tour. Time was not included as a covariate in any of the following analyses.

Outcome measures

After experiencing the VE, evaluation of each participant's spatial knowledge acquisition was assessed via exploring memory for landmarks, route knowledge and survey type spatial knowledge (cognitive mapping). The following outcome measures were administered in the following order so as to minimise any order effects; i.e. it was necessary to be aware of the effect of exposure to one outcome measure may have on subsequent performance on another.

The evaluative tools in the order they were administered were:

1) Free-recall for remembered landmarks. Participants were asked to list all of the distinctly identifiable landmarks, features and places they could remember from the VE but asked not to include any general or generic terms such as, 'trees', buildings', 'roads' etc.

2) Participants were asked to draw a sketch-map of the VE, the focus of which was the road layout. They were told that they could include other features if it helped them, but that the main focus of interest was the accuracy of their representation of a 'roadmap' of the VE. Two independent non-specialist confederates rated the sketch-maps. They were asked to rate the sketch maps on how useful they would be in navigating the road system of the VE using the following 4-point scale:

4 = highly useful; 3 = moderately useful; 2 = vaguely useful; 1 = not at all useful.

3) A computer based task, requiring participants to point to five unseen locations from a central point within the VE (*cf.* Foreman et al, 2003). The locations were buildings adjacent to the start and terminal points of each route. They were easily identifiable as each had a large sign on the front as illustrated in Figure 8.4. Pointing Error (PE) scores, the cumulative differences between the true directions of the target locations and participants' indicated directions, measured in degrees were calculated to evaluate performance.

4) A forced choice questionnaire with 10 items (see Appendix 1) required participants to indicate the direction of travel to a target location from a described current location. Five of the items were 'on-route', that is, the start point and target location were both on (connected by) one of the marked routes that participants were required to following during exploration. The other five items were 'off-route', that is, the start point and target location were not connected via one of the marked routes followed by participants during exploration. On-route items were designed to examine route knowledge, whilst off-route items were designed to examine survey type knowledge.

5) Participants were given an A4 sheet of paper with the road layout of the VE printed on it and asked to indicate as accurately as possible, by marking the paper with the corresponding numbers, the positions of 8 predominant landmarks, selected according to their unique attributes, conspicuousness and distribution around the VE. Placement error scores were then calculated by measuring between the landmark positions indicated by the participants and

their true positions. These distances were summed to give Map Placement Error (MPE) scores.

In summary the five outcome measures generated the following dependent variables:

1. Number of landmarks remembered.
2. Sketch-map rating score.
3. Pointing Error (PE) scores.
4. Route questionnaire scores.
5. Map Placement Error (MPE) scores.

The independent variables used in the following analyses were 'Condition' (active / passive) and 'Exposure' (5x, 10x, 15x). Gender and responses to the short questionnaire (see above) administered to participants before participation in the study were not used as IVs in the final analyses as their inclusion did not contribute anything useful or interesting to the results.

Descriptive Statistics

Table 8.1: mean scores by Condition and Exposure

Landmark by	condition	N	mean	SD
	driver	27	9.48	4.24
	passenger	27	12.07	4.20
Landmark by	exposure	N	mean	SD
	5 tours	20	8.35	3.50
	10 tours	18	11.11	3.84
	15 tours	16	13.44	4.50
*mpe by	condition	N	mean	SD
	driver	27	56.01	22.43
	passenger	27	57.64	20.21
*mpe by	exposure	N	mean	SD
	5 tours	20	65.71	17.43
	10 tours	18	58.45	15.92
	15 tours	16	43.90	24.98
**pe by	condition	N	mean	SD
	driver	27	41.35	17.77
	passenger	27	41.10	17.49
**pe by	exposure	N	mean	SD
	5 tours	20	46.92	15.46
	10 tours	18	43.55	19.10
	15 tours	16	31.47	14.50

* MAP PLACEMENT ERROR SCORES. ** POINTING ERROR SCORES

Table 8.1 above, gives the mean number of landmarks remembered, the MPE scores (in millimetres) and the PE scores (in degrees) by Condition and by Exposure with related standard deviations and sample sizes.

The scores in table 8.1 above, were subjected to a 2 (CONDITION (active / passive)) X 3 (EXPOSURE (5tours, 10tours, 15tours)) analysis of variance (ANOVA). A significant main effect for condition was indicated for number of landmarks remembered, $F(1, 53) = 6.39$; $p < .02$. Inspection of the means indicates that passive participants remembered significantly more landmarks than their active counterparts.

The exposure condition was shown to have a significant effect for PE scores, F(2,53) = 3.96; p < .03, landmarks, F(2,53) = 8.08; p < .01 and MPE scores 5.40; p < .01. Bonferroni multiple comparisons indicated significant differences between 5 and 15 times exposure conditions for PE scores, p < .02; landmarks, p < 0.01 and MPE scores, p < .01 9 (see Figure 8.5 below).

Figure 8.5: landmarks, map placement error and pointing error scores by exposure

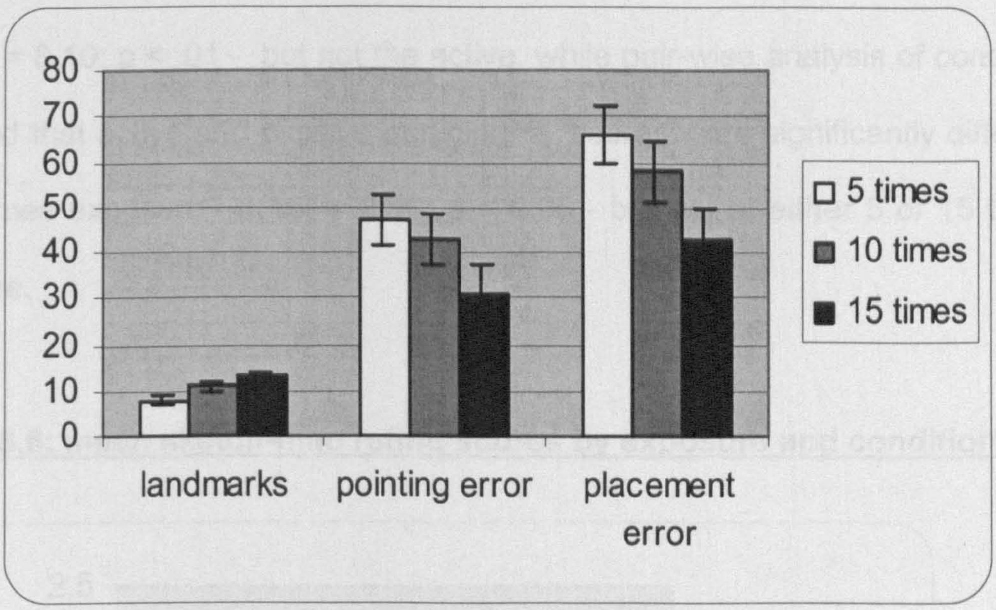


Figure 8.5 above, illustrates that performance on all three DVs improved as a function of Exposure. The number of landmarks remembered increased whilst both pointing error (in degrees) and placement error (in millimetres) decreased.

Sketch-map analysis

The sketch–maps drawn by the participants of the VE road layout were rated blind by 2 individuals, not otherwise associated with the study, using the 4-point scale and criteria described above (see Method). Inter-rater agreement was high, approaching 78%. The raters' scores for each participant were combined and averaged. A 2 (Condition) by 3 (Exposure), univariate analysis of variance yielded a significant main effect for exposure, $F(2,48) = 3.70$; $p < .05$ and a significant condition by exposure interaction, $F(2, 48) = 3.53$; $p < .05$. Bonferroni multiple comparisons indicated that ratings for maps drawn by participants in the 5 and 15 times exposure conditions, means 1.22 and 1.65 respectively, were significantly different from each other but neither differed significantly from the ratings for maps drawn by participants in the 10 times exposure condition (mean: 1.28). Post-hoc analysis of simple effects indicated that the effect of exposure was significant across the passive condition – $F(2,24) = 8.10$; $p < .01$ - but not the active, while pair-wise analysis of condition indicated that active and passive participants' scores were significantly different at 10 times exposure – $t(16) = 2.30$; $p < 0.05$ - but not at either 5 or 15 times exposure.

Figure 8.6: mean sketch-map rating scores by exposure and condition

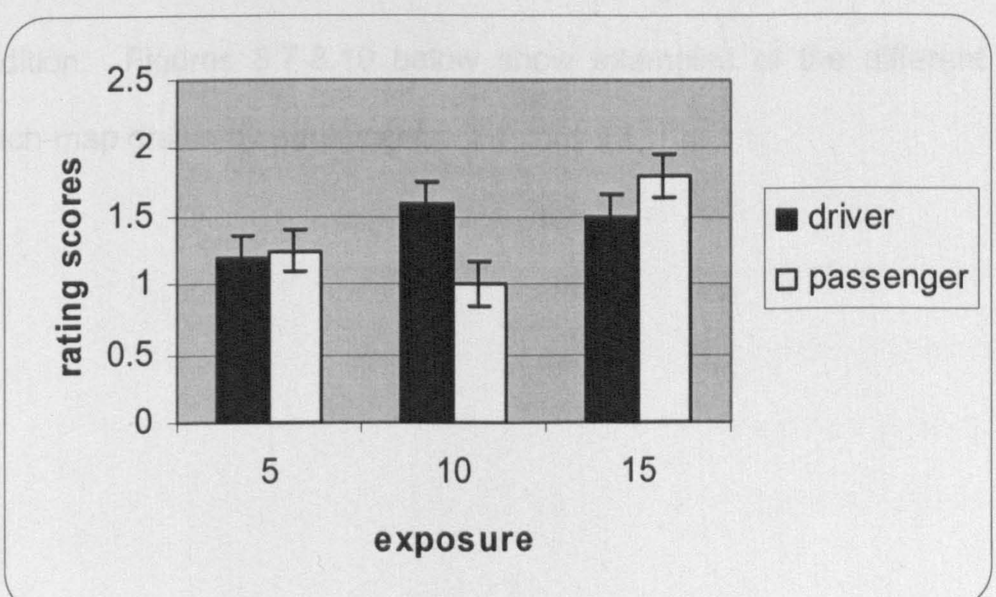


Figure 8.6 above, illustrates the exposure by condition interaction in terms of sketch-map rating scores. As can be seen the effect of condition is not

consistent across the levels of exposure while the effects of exposure are not consistent across the levels of condition.

The mean rating score for the utility of participants' sketch maps was low at 1.36, somewhere between being 'not at all useful' to 'vaguely useful', however 41 of the 54 (76%) maps drawn by participants showed a circuitous road layout reminiscent of the road layout of the VE. Of the remaining sketch maps, only 8 illustrated roads ways that did not form a circuit, while 4 were no more than lines drawn on paper and 1 was an apparent attempt to illustrate the spatial layout of the VE in terms of locations. Evaluating the sketch maps on these criteria, no pattern emerged to differentiate the independent variable groups. However, of the maps that were circuitous in nature, 14 contained a representation of a roadway in the form a figure of 8 with a roundabout at its centre, a feature of the virtual road layout, of these, 9 were drawn by participants in the active condition and 5 by participants in the passive condition. Figures 8.7-8.10 below show examples of the different types of sketch-map drawn by participants.

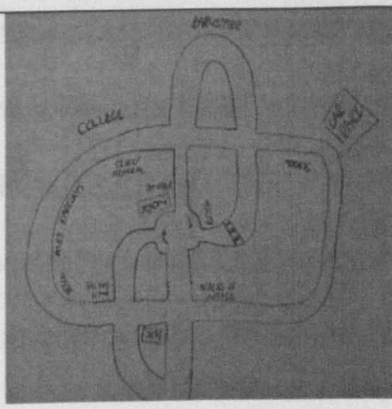


Figure 8.7

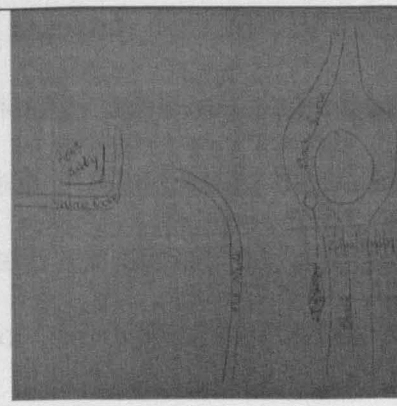


Figure 8.8

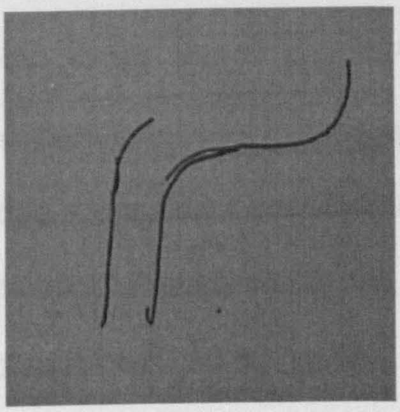


Figure 8.9

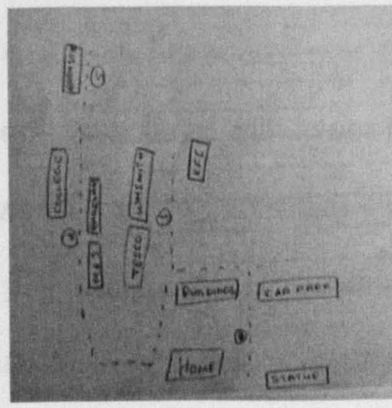


Figure 8.10

Figure 8.7 above, shows the best of the sketch-maps drawn by participants illustrating as it does a circuitous road layout with a figure of 8 and a roundabout at its centre. Figure 8.8, one of the sketch maps that did not illustrate the circuitous nature of the VE road layout but rather shows a section of roadway. Figure 8.9, shows one of the 5 sketch-maps that were not really representative of anything and Figure 8.10 shows the only sketch-map that tried to show the spatial relationships of locations within the VE but not the road layout.

Correlational analysis

Correlational analysis revealed a significant negative relationship between number of landmarks remembered and PE scores ($r = -0.361$, $df = 52$, $p < 0.01$)

and number of landmarks remembered and MPE scores ($r = -0.357$, $df = 52$, $p < 0.01$) whilst PE and MPE scores were also significantly positively correlated ($r = 0.246$, $df = 52$, $p < 0.05$). These results indicate a relationship between the three measures of knowledge about the VE and as scores on one of the measures improves so do scores on the other two.

Correlational analysis also revealed a significant negative relationship between sketch-map rating scores and MPE scores ($r = -0.525$, $df = 52$, $p < 0.01$) indicating that higher sketch-map rating scores were associated with lower MPE scores, and a significant positive relationship between sketch-map rating scores and landmarks remembered ($r = 0.337$, $df = 52$, $p < 0.05$). This indicates that higher sketch-map rating scores were associated with better memory for landmarks.

Sketch-map analysis (revisited)

In light of the associations indicated by the correlational analysis above, the sketch-map rating scores were re-analysed with the scores for the 10- times Exposure group removed. This was because the scores generated by this group did not fit the emerging pattern and may have been due to chance alone. A 2 (Condition) by 2 (Exposure), univariate analysis of variance yielded a significant main effect for Exposure, $F(1,36) = 7.30$; $p = .01$ and a non-significant effect for Condition, $F(1, 36) = 1.03$; $p > .05$.

Figure 8.11: mean sketch-map rating scores (y-axis) by exposure (5x/15x) and condition (driver/passenger)

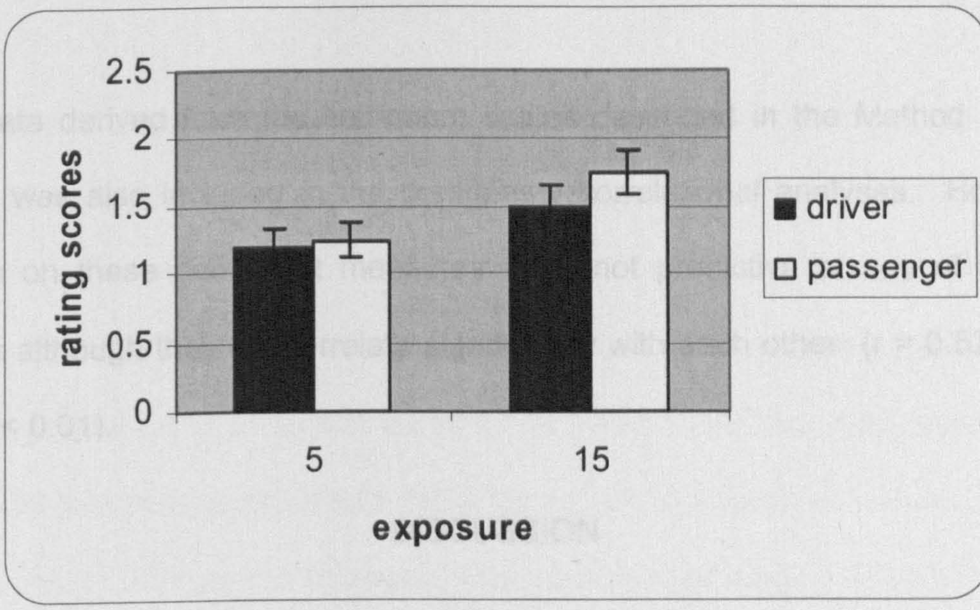


Figure 8.11 above, illustrates the significantly higher scores achieved by the sketch-maps drawn by participants who had travelled around the VE 15 times when compared to those who had travelled around it only five times. Figure 8.11 also shows that the maps drawn by 'passenger' participants scored arithmetically higher than did those drawn by 'driver' participants across exposure conditions.

Route-questionnaire scores were subjected to a multivariate ANOVA with Condition and exposure as the IVs and total-route-scores, off-route-scores and on-route-scores as the DVs. The analysis revealed that all route scores were equivalent across conditions. Correlational analysis revealed that none of the route scores correlated significantly with any of the other measures.

In addition to the independent variables considered in the above analyses, preliminary analyses also considered whether or not participants were car drivers and whether or not they were computer gamers. However these variables did not yield any significant results and for the sake of clarity were excluded from the final analyses as presented above.

The data derived from the self-rating scales described in the Method section above was also included in the preliminary correlational analyses. However, scores on these self-report measures were not predictive of any of the DV scores although they did correlate significantly with each other ($r = 0.523$, $df = 52$, $p < 0.01$).

DISCUSSION

The following discussion will be divided in to two sections, first will be considered the findings relating to active and passive differences in spatial learning and second will be considered the findings relating to the microgenisis (knowledge changes with increasing familiarity) of spatial learning.

The hypothesis, that drivers would learn more about the spatial layout of the VE than passengers, was not supported as drivers and passengers performed equivalently on the measures of spatial learning administered after exploration. Drivers were no better than passengers at orienting themselves within the VE as evidenced by their statistically equivalent pointing error scores and did not form superior mental representations of the VE than passengers as suggested by their equivalent map placement error scores and sketch maps. The findings did indicate, however, that in line with the experimental hypothesis, memory for landmarks was affected by mode of exploration (active / passive), with passengers remembering significantly more landmarks than did drivers. This finding was inline with the results of Attree et al (1996) who found that passive observation enhanced memory for objects encountered within a VE.

The study attempted to recreate the scenario in which a driver and passenger locomote around a novel small town centre, all be it in VR, as it was believed, based on previous research (Appleyard 1970; Hert and Bertzok 1982 and others), that this would give us the optimum situation in which to examine active / passive differences in spatial learning. It also sought to further facilitate the differences hypothesised would become evident, by making the learning task implicit rather than explicit to negate the possible confounding effect of passive participants paying unusually "high attention" to the learning task, identified by Wilson et al (1997) and Wilson (1999) (see above) when the nature of subsequent spatial tests are previously known. Participants in both conditions were instructed to attend to the VE only, but not given any specific instruction to attempt to learn the layout or content of the VE. This approach meant that our comparison was of physical activity in terms of control and action, with passivity in relative isolation from other possibly confounding cognitive variables related to intentional learning.

Yet, despite implementing favourable experimental procedures the current study did not support the hypothesis that active exploration of an environment leads to better spatial learning than more passive experience of an environment. Indeed, as predicted, in some instances it appears as if passive experience is beneficial in terms of remembering landmarks. Two possible contributory factors for the findings were identified, one was the purposelessness of the exploration undertaken by participants', and two was that active participants were not permitted to explore freely.

Whilst this approach left drivers with control over decisions to move or not to move (Hart and Berzok 1982) allied to the sensori-motor experience of manipulating the input device, their activity was not practical, i.e. it had no known purpose or outcome as it would have in reality. For instance, we do not drive or walk to work for the sake of driving or walking; there is a purpose to the activity. According to Cohen and Cohen (1985) activity in space is generally linked with other cognitive and social concerns providing purpose and a conceptual theme to the activity and the use of spatial information in the service of the theme or purpose. Therefore, it could be argued that the current experiment has demonstrated that when all other things are equal, activity for activity's sake is no more beneficial for learning the layout of a VE than being a passenger.

The second factor identified as possibly contributing to the current findings was that active participants did not explore freely, rather they were required to follow road markings that guided them around the VE in a specific sequence. The purpose of this procedure was to ensure that all participants were exposed to all areas of the VE. However, in retrospect this approach may have forced participant drivers to focus in so tightly on the road markings that they failed to observe or encode, or both, other features of the environment. Farrell, et al (2003) who found an advantage for active VE explorers over passive ones, in terms of spatial learning, had their passive participants follow a line around the experimental VE whilst their active participants explored freely. It could be argued that it was perhaps the imposition of having to follow a line rather than passivity per se that disadvantaged the passive explorers in their study. Obviously, in the current study, as drivers became more familiar with the routes, their reliance on the road markings to guide them reduced and their ability to 'look around' at other features of the VE increased. However, anecdotal observational evidence suggests that this process was subject to a high degree of variability, with some drivers seemingly unable to 'look up' from the road markings during the duration of their time exploring the VE. Wilkie and Wann (2003) found that participants required to visually 'track' the middle of a virtual roadway whilst moving along it made smaller steering errors than participants who were allowed an active 'free' gaze. This suggests that driver participants here may have been using the road markings not only to guide them around the VE but also to aid steering, and the extent to which this strategy was utilised may have been dependant on how confident participants felt using the steering wheel input device.

In light of the above considerations it was hypothesised that having drivers follow road markings around the VE, with so much of their attentional efforts focused on them, may have been a contributory factor in drivers not benefiting from activity as expected. Added to which, the advantage hypothesised for passenger participants in terms of memory for landmarks may have been exaggerated because drivers may have failed to look up from the road markings to observe the landmarks around them.

Therefore, apart from the predicted finding that passengers would have an advantage in terms of memory for landmarks, the current study failed to yield any evidence to support the hypothesis that activity is advantageous for spatial learning. Two suggestions have been made as to why this may be the case. First is that exploration of the VE had no purpose as far as participants were concerned, and second is that drivers' attention may have been so focused on the road markings that they did not engage with other features of the VE. These two factors may have affected the outcome in isolation but also it could be argued that in combination, drivers, with no obvious purpose to their explorations focused even more on following the road markings than might have been expected.

Despite not finding the advantages predicted for activity, the current study did indicate the predicted benefits of familiarity for spatial learning. The effect of length of exposure was strong and consistent for both drivers and passengers, and performance levels improved, in an almost linear fashion as a function of exposure. As experience of the VE increased so did participants' memory for landmarks which increased from over 8 to over 13 (landmarks remembered) between 5 and 15 times exposure and participants' representations of the VE as evidenced by a reduction in pointing and map placement error scores, 47 to 31.5 degrees and 6.6 to 4.4 centimetres respectively. These findings were in line with the experimental hypothesis and appear to indicate a very robust effect. Performance levels on each of the measures also correlated strongly together between groups, as would be expected given the results of the ANOVA but not within groups. This means that individual scores within the exposure groups did not correlate on the measures but that scores across groups correlated reflecting the improvement as a function of exposure.

From these findings it is difficult to see any evidence supporting Siegel and Whites' (1975) model for spatial learning, since landmark and configurational knowledge seem to have improved concurrently, indicating a parallel learning process rather than a sequential one. For instance, examination of the performance levels of participants in the shortest exposure condition indicates that configurational learning had taken place whilst landmark learning was still developing. These findings appear to be inconsistent with a model of spatial learning which posits that in the early stages of familiarity with an environment only knowledge of landmarks as qualitatively non-metric knowledge manifests (Montello 1998). This implies that participants should not be able to point to unseen locations, as this requires understanding of the metric layout of the environment. That such an understanding should manifest so rapidly and in conjunction with landmark knowledge rather than subsequent to landmark knowledge is suggestive of the first tenet of what Montello (1998) called his 'New Framework' for the development of spatial knowledge. In this Montello argues that:

"*There is no stage at which only pure landmark or route knowledge exists, knowledge that contains no metric information about direction and distance (relative locations of places). Metric configurational knowledge begins to be acquired on first exposure to a novel place*" (p.146).

One possible criticism of what is suggested here, in relation to the current findings is that the minimum exposure condition may have been long enough for participants' knowledge to move between the qualitatively distinct landmark and configurational stages as suggested by Siegel and White (1975). This explanation, however, seems unlikely since participants spent no more than 30 minutes exploring the novel and complex large-scale environment barely enough time for route knowledge to manifest let alone survey knowledge. However, to further investigate this issue by introducing an exposure level smaller than the current minimum would be relatively straightforward.

The way in which spatial learning in the current study appears to develop as a function of exposure, is also more supportive of other aspects of Montello's (1998) new framework' for spatial learning than of Siegel and White's (1975) three stage model. Montello's second tenet states that:

"As familiarity and exposure to places increases, there is a relatively continuous increase in the quantity, accuracy and completeness of spatial knowledge (quantitative rather than qualitative shift). Although this knowledge may become fairly accurate and extensive rather quickly, increases may continue indefinitely with further experience" (p. 146).

Inspection of the current findings reveals a pattern of acquired knowledge that appears to demonstrate Montello's second tenet in that each increase in exposure facilitates increases in performance on both the landmark and configurational measures. These performance increases appear to be continuous with no evidence of steps as one might expect if different stages were being reached. An objection to this thesis might be that the maximum exposure condition was insufficient to provide evidence for Siegel and White's (1975) stage theory and that longer exposure may have promoted such a large jump in performance on the configurational measures as to be considered a step. However, this seems unlikely when compared to the alternative explanation that spatial learning takes on configurational data from the start and changes in spatial knowledge related to familiarity are relatively continuous and quantitative rather than qualitative in nature (Montello 1998).

In addition to the measures of spatial learning discussed so far, participants were also asked to draw sketch-maps of the VE to demonstrate their understanding of its layout. The maps were evaluated on their utility along a 4-point scale, maps that were considered better for wayfinding scored more highly. In general however, the quality of the sketch-maps was poor with the mean score achieved being only 1.36, somewhere between 'not at all useful' and 'vaguely useful'. Inferential analysis indicated a significant effect for exposure and a significant exposure by condition interaction. However, post hoc tests did not support the main effect or shed any light on a meaningful explanation for the interaction, these findings are illustrated by Figure 8.2 in which it can be seen that the means across the three exposure conditions are not all in the same direction. However, inspection of Figure 8.2 illustrates that maps drawn by participants in the 15 times exposure condition rated more highly than those drawn by participants in the 5 times exposure condition. A further analysis was conducted with the scores for the 10 times exposures group filtered-out because they made no theoretic sense and were contrary to the emerging pattern, in other words they could be explained by chance. This analysis indicated that the advantage seen in Figure 8.2 for participants in the 15 times exposure condition over participants in the 5 times exposure condition was in fact significant whilst also indicating an arithmetical but not significant advantage for passenger participants over drivers (see Figure 8.3).

Despite the generally poor standard of sketch-maps, the sketch-map rating scores had a significant negative correlation with MPE scores and a significant positive correlation with number of landmarks remembered indicating that participants who draw better maps were also more accurate at placing landmarks on a map of the VE and also remembered more landmarks. These findings obviously support the notion that sketch-maps convey spatial knowledge and that better spatial knowledge leads to more accurate sketch-maps. However, they also appear to indicate that people may know more about the spatial layout of an environment than they are able to express by drawing a sketch-map. This would certainly appear to be the case currently considering the poor general standard of sketch-maps compared to the generally good levels of spatial knowledge demonstrated on the other measures. Sketch-maps as a performance measure may therefore be problematic, as they may be difficult for individuals to produce and may not be a true reflection of a person's spatial knowledge of an environment. A pertinent illustration of this point is the observation made by Thorndyke and Hayes-Roth (1982) who suggested that people living in areas with irregular, as opposed to block, street topography experience difficulties in drawing maps of their neighbourhoods even when they have developed vivid and accurate memories of the routes they are attempting to reproduce. As can be seen from Figure 8.1 the street topography of the VE of the current study is irregular in that it is not of a block type formation. However, despite this additional consideration there were a small number of relatively high quality maps drawn by participants and this would appear to support the suggestion made Liben (1981) that the quality of "*spatial products*" such as sketch-maps is highly dependent on the individuals ability to represent spatial knowledge using that particular medium.

A qualitative evaluation of the sketch-maps revealed that 41 of the 54 (76%) maps drawn by participants showed a circuitous road layout vaguely reminiscent of the road layout of the VE. Of the remaining sketch-maps only 8 illustrated roads ways that did not form a circuit, while 4 were no more than lines drawn on paper and 1 was an apparent attempt to illustrate the spatial layout of the VE in terms of unconnected locations. Evaluating the sketch maps on these criteria, no pattern emerged to differentiate the independent variable groups. However, of the maps that were circuitous in nature 14 contained a representation of a roadway in the form a figure of 8 with a roundabout at its centre, a feature of the virtual road layout, and of these, 9 were drawn by participants in the active condition and 5 by participants in the passive condition.

Performance on the route-questionnaire (see Appendix 1) was extremely poor over all and in some cases participants scores were below chance levels. Current findings and previous research indicate that route knowledge must have been acquired at least to some extent and that therefore, there may have been problems with the instrument and or the approach. One of the contributory factors may have been that, taken out of the context of the environment itself route judgments are more difficult to make and may not be a true reflection of route or wayfinding knowledge within the environment. In addition to which, whilst every effort was made to make the start-location descriptions as accurate as possible, salient information available to individuals in the VE only, may have been omitted. Another factor that may have contributed to the depressed scores on this measure was that many of the participants did not have English as their first language and therefore may also have had additional difficulty in understanding the start-location descriptions, obviously impacting on their abilities to make informed directional choices. Clearly the best way in which to overcome any language and context problems related to measures of route knowledge is to have people demonstrate their acquired route knowledge by moving between locations within the test environment.

Summary

The main objective of the current study was to recreate the driver / passenger scenario in order to replicate a previous observation (Appleyard, 1970; Hert and Berzok, 1982 and others), that drivers learn more about the layout of environments than do passengers. However, the current study did not support the hypothesis that active exploration of an environment leads to better spatial learning than more passive experience of an environment. Indeed, in some instances it appears as if passive experience is more advantageous, e.g. in terms of remembering landmarks. Two possible contributory factors for the findings were identified, one was that exploration was not goal driven and two was that active participants were not permitted to explore freely and may have been too focussed on following signs to guide them around the VE. A follow-up study in which active explorers would engage in purposeful and free exploration would address these issues.

In examining active / passive differences evidence for the microgenic development of spatial knowledge was also considered and evidence to support a parallel process as proposed by Montello (1998), as opposed to a serial process as proposed by Siegel and White (1975) was found. This indicated that landmark, route and survey knowledge develops together, improving quantifiably with environmental familiarity, and does not develop independently in hierarchical stages.

Two of the five measures, sketch-maps and route-questionnaires, did not appear to reliably reflect participants' spatial knowledge of the VE. The quality of the sketch-maps was extremely poor, with a few notable exceptions and although the rating scores did correlate with two of the other measures it was concluded that they did not adequately reflect participants' knowledge of the VE. Scores on the route-questionnaire may have been confounded by the inability of language to convey all the spatial detail required for participants to make informed directional choices and the fact that many participants did not have English as their first language may have compounded this problem. A follow-up study could utilise measures that are more reliable and better allow participants to express their spatial knowledge. For instance, participants could be asked to travel between locations within the VE to express route knowledge and to select a map of the VE from a number of choices to demonstrate configurational knowledge.

Chapter 9

Experiment 7.

Self directed and task specific exploration of virtual environments does not enhance spatial learning

INTRODUCTION

In Experiment 6 the aim was to explore active / passive differences in spatial learning by replicating the driver / passenger scenario often cited by researchers as demonstrating the benefits of active exploration for spatial learning. The findings of Experiment 6 did not, however, find any evidence to support the hypothesis that drivers, that is to say active explorers, would learn more about the spatial layout of a VE than passengers, that is to say passive observers. Two factors identified as possibly contributing to these findings were that (1) exploration was guided in that drivers had to follow road markings around the VE i.e. could not explore freely; and (2) exploration was not goal-driven i.e. had no purpose other than to follow the road markings as far as the participants were concerned. It was concluded that the combination of these two factors might have prevented participants in the driver condition from benefiting from activity as they otherwise might.

Beck and Wood (1976) suggest that in addition to travel mode, the learning situation also influences spatial cognition. In particular, they identify self-directed as opposed to guided exploration and goal-oriented as opposed to incidental learning as factors influential in shaping spatial learning. Previous studies such as those of Peruch, Gaunet, Giraudo and Thinus Blanc (cited in Peruch and Gaunet, 1998) and Gaunet, Vidal, Kemeny and Berthoz (2001) have yielded contradictory findings in respect of guided active exploration versus passive exploration. For instance Peruch et al (cited in Peruch and Gaunet, 1998) found that guided active participants were better on a task requiring them to relocate original locations after markers had been removed than passive participants who had experienced the experimental VE via a video recording. However, the study of Gaunet et al (2001), in which active participants' explorations were also guided, failed to reveal any advantage for active explorers over passive observers on a scene recognition task, estimate of direction task and a sketch-map task. They concluded that in VEs visual flow might suffice for spatial learning, making motor control less important.

In addition to being guided, exploration of the VE in Experiment 6 was not goal driven and it was suggested that because participant exploration of the VE was purposeless, active participants might not have benefited from activity as they would in a natural setting. This proposition is supported by the suggestion of Hart and Berzok (1982) that research involving 'non-purposeful' tasks has underestimated the competencies of participants, in terms of developing spatial knowledge. They go on to argue that in a real world setting they would expect humans to better organise the more complex spatial information than they are exposed to in laboratories because they can explore freely (rather than being led), select personally relevant land marks and are highly motivated to do so.

The question of motivation can also be a factor in whether or not spatial learning is implicit or explicit. Spatial learning in Experiment 6 was incidental in that participants were unaware of the nature of the study and were not asked to make any effort to remember the spatial layout of the VE. This approach was adopted because it had been previously suggested that passive participants raise their cognitive effort beyond normal if the nature of the task is explicit and this in turn masks the benefits of activity (Wilson et al 1997). However, Wilson (1999) in a follow up study concluded that the previous findings of no difference between active and passive participants on measures of spatial learning might not have been due to passive participants paying an unusually high degree of attention to the task. Findings related to the relative importance and utility of implicit and explicit spatial learning is, therefore equivocal. For instance Herman, Kolker and Shaw (1982) found that there were no differences between children in intentional and incidental memory conditions on a task requiring them to reconstruct a model town they had previously explored.

The findings of Experiment 6 did not reveal any active / passive differences in spatial learning of a VE and it was hypothesised that this may have been due to some of the experimental procedures put in place. The aim of the current study was to further investigate active / passive differences in spatial learning by partially replicating Experiment 6 and modifying the experimental procedures. Where exploration was guided and had no obvious purpose (for participants) in Experiment 6 it is self-directed and goal-driven here. In addition to which, the spatial learning task was also made more explicit here than it was in Experiment 6. It was hypothesised that the implementation of these changes would facilitate active participants in demonstrating the benefits of activity for spatial learning or, if this proved not to be the case, then the current study would add to the body of knowledge concerning the relative benefits of goal-driven, self directed exploration in an explicit spatial learning context.

Furthermore, two of the measures used in Experiment 6 can be criticised for not being effective at demonstrating participants true levels of spatial learning, these being sketch-maps and a forced-choice questionnaire requiring participants to make a directional decision towards a target location based on a description of their current location. Performance levels on these measures were extremely low and did not correlate with the other measure used (see discussion of Experiment 6 for details). In the current study the sketch-map task was replaced with a task requiring participants to select a map depicting the road layout of the VE from a number of choices. This task still requires participants to draw on their mental representations of the VE layout in order to select the correct map but it is not dependent on drawing ability. Farrell, et al (2003) suggest that tasks requiring participants to make directional judgements may not be indicative of actual navigational ability, therefore the route questionnaire was replaced by a task requiring participants to navigate in the VE between a number of Start and Target locations. Another advantage of this task is that it is not dependent on language, a possible confounding variable like drawing ability, to convey spatial information.

In Experiment 6 it was hypothesised that active / passive differences may manifest as a function of level of familiarity with an environment and in order to investigate this, participants were allocated to one of three different levels of exposure conditions. This procedure also enabled an investigation into how spatial learning per se developed and yielded some interesting results.

However, the hypothesis relating to active / passive differences was not supported and since the main focus of the investigation concerns active / passive differences in spatial learning, participants in the current study were segregated on this basis only. This approach also makes sense in terms of the goal driven nature of exploration in the current study, as will be made clear below.

In summary, therefore, the current study is a partial replication of Experiment 6 with the main procedural differences being that exploration is self-directed as opposed to guided and goal-driven as opposed to purposeless. In addition to this, the learning task is more explicit than in Experiment 6 whilst two of the measures from Experiment 6 have been dropped in favour of two new measures thought to give a better indication of participants' true levels of spatial learning. It was hypothesised that with the implementation of these changes active participants would be better able to demonstrate the benefits of activity and learn more about the spatial layout of the VE than their passive counterparts.

METHOD

Participants

Thirty-four undergraduate psychology students attending a London University participated in exchange for course credits. There were 27 females and 7 males with a combined mean age of 23 years and a range of 18 to 38 years. All had normal or corrected to normal vision. Twenty were licensed car drivers and 12 regarded themselves as regular computer gamers.

Setting

The experiment was run in a small office (approx. 3 x 3 metres) lit by fluorescent lighting and provided with natural light through a large window. The room contained 2 desks, 2 chairs and 2 filing cabinets in addition to the experimental apparatus.

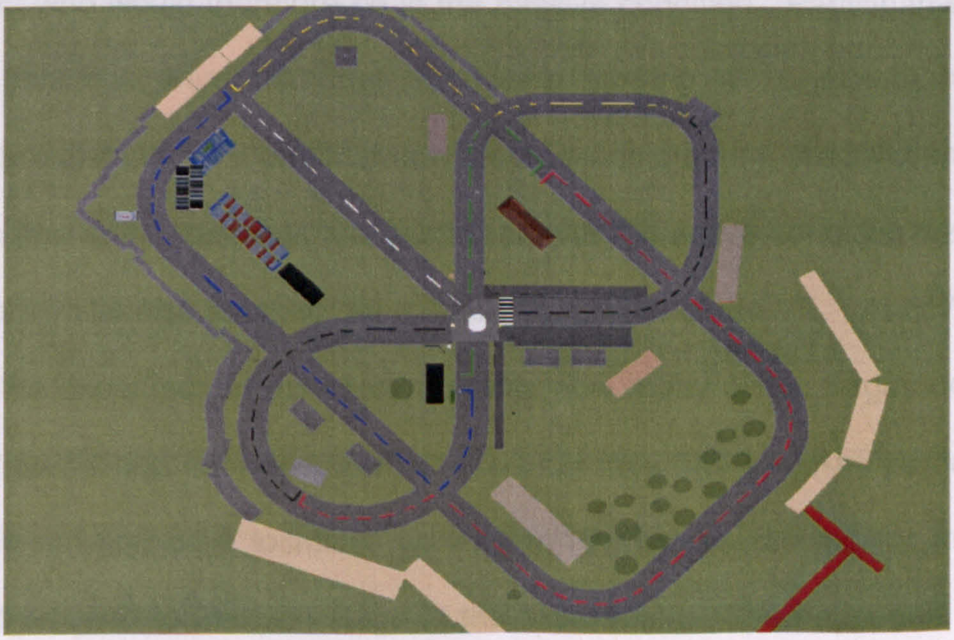
Apparatus

The VE (created using SuperScape 3-D virtual reality software) was run on an IBM compatible laptop computer (Toshiba Satellite Pro 4600) with a Pentium 3 processor. The visual display was via a 14-inch colour television monitor (Minoka MK 1499) with video in and video out facilities whilst the input device was a Thrustmaster steering wheel and pedal arrangement providing directional, acceleration and braking control. The steering wheel was fixed to the edge of a desk with the pedal unit sitting on the floor underneath the desk. The virtual explorations of participants in the active / driver condition were recorded using a Sony Handy-cam Digital Video recorder (DCR-PC9E PAL).

The virtual environment used in the current study was basically the same as that used in Experiment 6 without the route-defining road markings and with a few minor road, and building-position modifications (see Figures 9.1 and 9.2). The road layout modifications were carried out to reduce the number of route options available to participants and to make the shortest routes between specific locations more obvious. In addition to which some buildings were added or repositioned to prevent participants from being able to see target locations from test points within the VE.

Figure 9.1: bird'seye view of the layout of current VE

Figure 9.2: bird'seye view of the layout of the VE used in Experiment 6



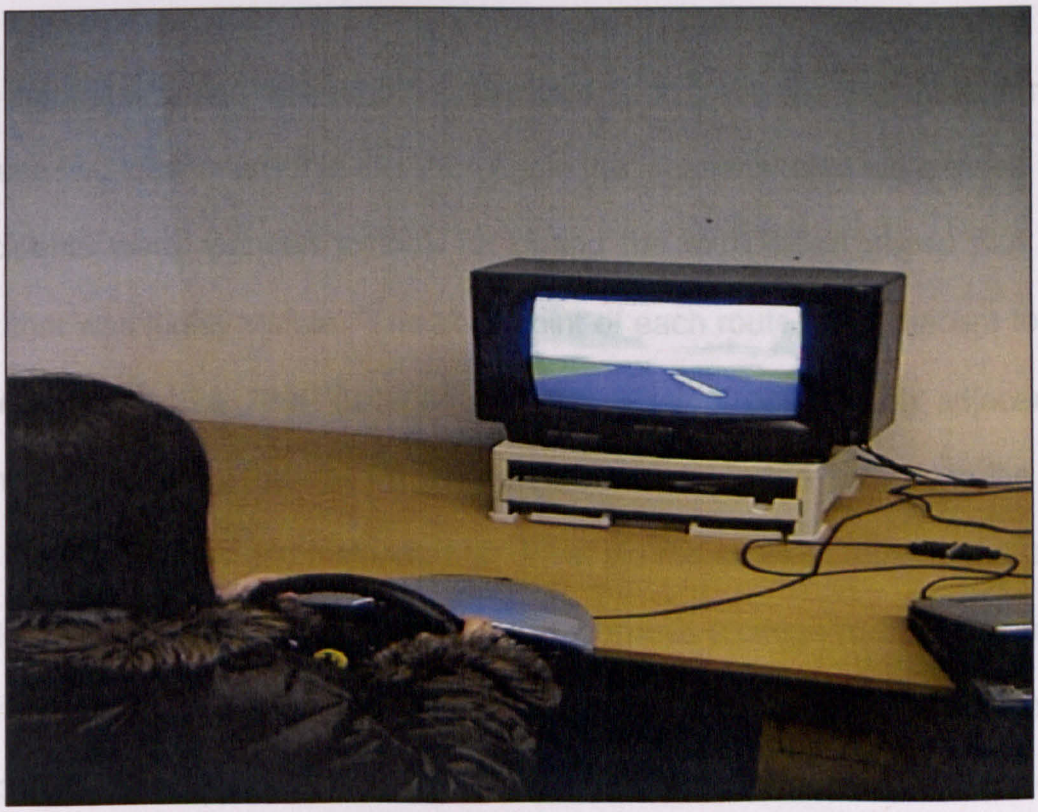
Figures 9.1 and 9.2, above illustrate the differences between the VE used in the current study and that used in Experiment 6. As can be seen allterations included removing the virtual road extending from the roundabout to the NW end of the VE, adding and repositioning some buildings and trees and removing the road markings indicating the routes participants in Experiment 6 had to follow. However, despite the modifications the two VEs were essentially the same, and conveyed the same generic small town centre.

Procedure

Participants experienced the VE in either the active (driver) or passive (passenger) condition. Participants in the active condition were instructed that they would have 10 minutes to explore the VE and that within that time they must locate 4 readily identifiable locations (Home, College, Babysitter and School), whilst also trying to get to know the layout of the VE. The explorations of each active participant were videotaped and shown to the following participant who would therefore be in the passive condition. Participants in the passive condition were told that they were viewing a 10 minute tape of somebody exploring a VE and that they were to look out for 4 readily identifiable locations (the same locations that participants in the active condition were told to look for) whilst also trying to get to know the layout of the VE. At 5, 7 and 9 minutes the experimenter asked participants how many of the target locations they had found and informed them of the time they had left. Any participants that could not find all 4 locations within the 10 minutes allowed for the task could not proceed to the next stage of the experiment. This happened in only one instance.

Before experiencing / exploring the experimental environment all participants were given instruction on how to use the input device - the same input device as that used in Experiment 6 - and then 'drove' for up to 5 minutes, or until they reported that they felt comfortable, around a virtual road circuit (see Figure 9.3 below). After adjusting to the sensitivity of the controls in terms of turn and acceleration all participants completed this task with ease.

Figure 9.3: a participant familiarises herself with the input device



Outcome measures

After experiencing the VE, evaluation of participant's spatial knowledge acquisition was made using several measures. As in Experiment 6, outcome measures had to be administered in a particular order so as to minimise the effect that exposure to one outcome measure may have on subsequent performance on another. The evaluative tools, in the order they were administered were:

1. A computer based task, requiring participants to point to unseen locations from a central point within the VE. The locations were those participants were required to look for during the exploration phase, plus one other. Pointing error (PE) scores; the cumulative difference between the true directions of the target locations and participants' indicated directions, measured in degrees, were calculated to evaluate performance on this task.

2. A computer based task-requiring participants to travel via the shortest route between two locations within the VE. Again the locations used were those four, participants were required to look for during the exploration phase plus one other that was highly visible. The start point of each route was adjacent to one of the locations, i.e., the 'college' with the terminal point being adjacent to another location, i.e., 'home'. Participants were 'transported' directly to the start point of each journey and instructed to 'drive' via the shortest route to the target location. Participants had to make 4 such journeys (college to home; home to the red statue; red statue to the baby sitter; baby sitter to the school). Participants' displacements during this task were recorded and subsequently scored using the following criteria: 0 points for failing to reach the target location within the permitted time; 1 point for indirectly finding the target location; 2 points for finding the target location directly but not via the shortest route; and 3 points for finding the target location via the shortest route. Participants' points for each journey were added together to give them their overall 'Route Scores'.

3. Participants were shown 5 road maps, that is, maps showing road layouts but no other features, and asked to select the correct one for the experimental VE.

4. Each participant was given an A4 sheet of paper with the road layout of the VE printed on it and asked to indicate as accurately as possible, by marking the paper with the corresponding numbers, the positions of the 4 locations they were asked to find during the exploration phase of the study. Placement error scores were then calculated by measuring between the positions indicated by the participants and the true location positions. These distances were summed to give 'Map Placement Error Scores".

In summary the four outcome measures generated the following dependent variables:

1. Pointing Error scores (PE).
2. Route scores.
3. Road map choice.
4. Map Placement Error scores (MPE).

The independent variables used in the following analyses were 'Condition' (active / passive) and whether or not participants drove a car, 'Driver?' (driver / non-driver). Gender and previous computer use were not included as variables in the data analysis reported here.

Descriptive Statistics

Table 9.1: descriptive statistics for condition and driver? by pointing error scores (PE), map placement error scores (MPE) and route scores

	Driver?	Condition	Mean Scores	SD	N
PE Scores:	driver	Active	302	152.80	10
		Passive	301.9	80.70	10
		Total	301.95	118.93	20
	non-driver	Active	313	97.45	7
		Passive	348.14	153.42	7
		Total	330.57	124.82	7
	Total	Active	306.53	129.33	17
		Passive	320.94	114.19	17
		Total	313.73	120.36	34
MPE Scores:	driver	Active	22.90	13.66	10
		Passive	29.35	14.42	10
		Total	26.12	14.06	20
	non-driver	Active	35.64	15.30	7
		Passive	37.43	8.88	7
		Total	36.53	12.05	14
	Total	Active	28.15	15.32	17
		Passive	32.68	12.78	17
		Total	30.41	14.08	34
Route Scores:	driver	Active	8.00	2.11	10
		Passive	5.00	2.05	10
		Total	6.50	2.54	20
	non-driver	Active	5.00	2.52	7
		Passive	6.57	2.15	7
		Total	5.78	2.39	14
	Total	Active	6.76	2.68	17
		Passive	5.64	2.17	17
		Total	6.20	2.47	34

Table 9.1 above, shows PE scores (in degrees), MPE scores (in millimetres) and Route scores, by Condition (active / passive) and Driver? (driver / non-driver).

Inferential Analysis

The scores in table 9.1 above, were subjected to a 2 (condition (active / passive)) X 2 (driver? (driver / non-driver)) ANOVA.

A significant main effect for driver was indicated for MPE Scores, $F(1, 30) = 4.93$; $p < 0.05$. Inspection of the means indicates that participants who were car drivers were more accurate at indicating the positions of target locations on a map, in both the active and passive conditions, than participants who had indicated that they were not car drivers.

A significant interaction for driver by condition was indicated for route scores, $F(1.30) = 8.98$; $p < 0.01$. Tests for simple effects showed that drivers in the active condition scored significantly better on route finding than did non-drivers.

Correlational analysis revealed a significant negative relationship between route scores and MPE scores ($r = -0.42$, $df = 34$, $p = 0.01$). These results indicate that lower MPE scores are associated with higher route scores. Performance on PE scores did not significantly correlate with any of the other measures.

Just over 35% of all participants selected the correct roadmap of the VE from the 5 choices they were offered. This equated to 12 out of 34 participants overall and broke down as 6 out of 17 participants in the active condition and 6 out of 17 in the passive. Therefore, 1 in 3 participants selected the correct roadmap regardless of which condition they were in. Although not indicating any active / passive differences the correct map was selected almost twice as often as would be expected by chance alone, that is 35% of the time as opposed to 20%.

The map selection variable was collapsed from 5 possible responses to 2, correct and incorrect and used as the IV in the following 3 t-tests, in which the DVs were, Pointing Error scores, Map Placement Error scores and Route scores.

Table 9.2: map choice by MPE, PE and route scores

	Map-Choice	N	Mean	SD	SE
MPE scores	Correct	12	23.875	13.934	4.023
	Incorrect	22	33.977	13.113	2.795
PE scores	Correct	12	321.08	151.91	43.85
	Incorrect	22	309.73	103.10	21.97
Route scores	Correct	12	7.583	2.314	0.668
	Incorrect	22	5.454	2.262	0.482

Table 9.2 above, shows the descriptive statistics for map choice by pointing error scores map placement error scores and route scores.

Independent groups t-tests indicated a significant difference between participants who correctly identified a road map of the VE and those who did not in terms of MPE scores, $t(32) = -2.10$, $p < .05$ and Route scores, $t(32) = 2.60$, $p = .01$ but not in terms of PE scores. Inspection of the means (see table 9.2) reveals that participants who correctly identified a road map of the VE were also more accurate at indicating the positions of target locations on a roadmap of the

VE, i.e. had lower MPE scores, and were also better at finding the shortest route between locations within the VE i.e. had higher route scores.

As PE scores did not significantly correlate with any of the other outcome measures or differentiate participants who correctly identified a road map of the VE, it was decided to compare these scores with the PE scores from Experiment 6 in which participants also had to point to 5 unseen locations, 4 of which were the same as in the current experiment.

In Experiment 6 participants experienced the VE under 3 'Exposure' conditions, they had to follow marked routes around the VE 5 times, 10 times or 15 times (see Experiment 6 Method section for details). In the current experiment participants explored the environment for 10 minutes searching for 4 out of the 5 locations they were subsequently asked to point to unseen. A One-way ANOVA was used to compare the PE scores of all participants, both active and passive, in the 5, 10 and 15 times conditions of Experiment 6 with the PE scores of all participants, both active and passive, in the current study. The ANOVA was highly significant, $F(3,84) = 10.12$; $p < .01$. Bonferroni multiple comparisons indicated that participants' PE scores in the current study were significantly different to the PE scores of participants in all 3 of the exposure conditions of Experiment 6. Inspection of the means in Table 9.3 below reveals that current study PE scores were higher in all cases, indicating that participants in the current study were not as accurate at pointing to the unseen locations as participants in any of the exposure conditions of Experiment 6.

Table 9.3: descriptive statistics for PE scores by exposure conditions of Experiment 6 (5,10 & 15 times) and current study, 10 minutes.

Exposure	N	Mean	SD	Min	Max
5 times	20	234.63	77.29	121	377
10 times	18	217.78	95.48	87	426
15 times	16	157.38	72.44	60	296
10 minutes.	34	313.74	120.35	87	616

DISCUSSION

The procedural changes made between the current study and Experiment 6 did not affect the findings in terms of the active / passive comparison. As in Experiment 6 the current study did not yield any results to support the hypothesis that active explorers, that is to say participants who 'drove' around the VE would learn more about the spatial layout of the VE than passive observers, that is to say participants who were 'passengers'.

In Experiment 6, exploration was guided but not goal driven and learning was implicit in that participants were not expressly directed to learn the layout of the VE. In the current study exploration was free and goal driven, whilst learning was more explicit in that participants were directed to "get to know" the VE. These changes did not, however appear to make any difference in the relative abilities of active and passive participants to learn the layout of the VE. Passive participants were as good as active participants at pointing to unseen locations within the VE, identifying the positions of locations on an outline map of the VE, and selecting the correct map of the VE roadway layout from a number of similar maps.

The current findings, along with those of Experiment 6, therefore demonstrate that under a range of exploration and learning conditions, activity in virtual environments may not be beneficial for spatial learning in adults as has been suggested by the findings of previous environmental studies indicating the benefits of activity in the real world (see above for details). It could be concluded that for adults at least, activity it not a necessary prerequisite for good spatial learning of virtual environments. Indeed previous real world experimental studies such as those of Siegel, Herman, Allen and Kirasic (1979), Feldman and Acredolo (1979), and Herman (1980) have all indicated that as humans age they become less reliant on self guided locomotion through space to form good spatial representations. However, another interpretation of the data, suggested by Sandamas and Foreman (2003), could be that humans have adapted to passively acquiring spatial information via 2-D media such as computer monitors or through watching television.

Interestingly, however, the current findings did indicate an advantage on two of the measures, for participants who had indicated that they were car drivers in the real world. These participants were significantly better than non-car drivers at indicating the positions of target locations on a map regardless of which condition they participated in - active or passive - and significantly better at route finding if they were in the active condition. These findings are of particular interest due to the predominant status of studies that have considered driver / passenger differences in spatial learning as indicating the benefits of activity, as discussed at length above. However, the current findings appear to suggest that car drivers may not be demonstrating the advantages of activity for spatial learning per se but may instead be demonstrating specific competencies related to being vehicle drivers.

This has implications for Appleyard's (1970) assumption that drivers learn more about their environment than those who travel as passengers. This was based on the quality of their sketch maps since he found that drivers drew more complete and coherent maps than passengers. Similarly, the current study indicates that car drivers are superior to non-car drivers at placing locations on a road map of the VE layout but that this, however, is not dependent on the condition under which they experienced the VE. Therefore, rather than demonstrating the benefits of activity for spatial learning the current findings may be demonstrating that car drivers are more familiar with and have a greater understanding of maps; following this logic perhaps the same could be said of the findings of Appleyard (1970). An observation made by Beck and Wood (1976) goes some way to supporting this position. They suggest that experience with conventional map use is a predictor for ability in using sketch maps as vehicles of expression for geographic knowledge in the same way as reading is related to writing. Therefore, if we deduce, that in general, car drivers are more likely to use and refer to maps on a regular basis than passengers, who by and large are not charged with navigational responsibilities, Beck and Wood's (1976) observations appear to be reinforced by the current findings and those of Appleyard (1970). However, such an assertion must be tempered by the fact that on a similar task in Experiment 6 no advantage was found for real world car drivers over non-car drivers at indicating the positions of target locations on a map.

The finding that real world car drivers in the experimental active condition were better at navigating routes within the VE than those in the passive condition suggests that route learning in a simulated urban environment is, for real world drivers at least, facilitated if the mode of exploration replicates that which they are most used to in the real world. In the current case it might be suggested that real world car drivers benefited more, in terms of spatial learning, when they were able to explore the VE by driving round it rather than viewing a video recording of another person driving around it, because in real life this is what they are used to doing. That is to say, car drivers are better able to learn routes around a VE when they have driven around it than when they are driven round it as passengers. Obviously based on such limited evidence this hypothesis needs further investigation. For instance should non-car drivers in the passive condition have benefited more in terms of spatial learning than non-car drivers in the active condition since they are more familiar with travelling as passengers? The answers to such questions would obviously have an impact on how best to utilise VEs as both investigative tools and training media.

As in Experiment 6, the current study revealed correlations between some of the measures used to evaluate spatial learning, specifically route scores and map placement error scores (MPE scores). The significant negative correlation revealed that as participant scores on the route finding task increased, error when indicating target locations on a map of the VE decreased. These findings, like those in Experiment 6, appear to indicate that different aspects of spatial learning develop in parallel as proposed by Montello (1998), rather than as part of a sequential hierarchical process such as that suggested by Siegel and White (1975). In particular, the current findings appear to indicate that route and configurational knowledge may develop in parallel rather than in series.

Participants in the current study were also required to identify the correct road map of the VE from a number of possible choices. Active and passive participants were not differentiated by performance on this task, but participants who correctly identified the map were also shown to have performed significantly better on the route finding task and the MPE task than participants who did not. These findings provide further evidence of a relationship between the different measures of spatial learning used in the current study.

However, this relationship between the measures of spatial learning was not evident for pointing error scores (PE scores) as they did not correlate with any of the other measures and did not differentiate participants who had correctly identified a map of the VE from those who did not. In Experiment 6, participants' also generated PE scores by pointing to unseen locations within the VE, however in this instance the PE scores correlated significantly with MPE scores and number of landmarks remembered. To further investigate why PE scores from the current study were not related to the other measures as they were in Experiment 6, PE scores across the two studies were compared. This comparison was justified based on the similarity between the two experimental environments and that four out of the five targets participants were required to point to, were the same in both experiments. The comparison indicated that PE scores for all participants (active and passive) in the current study were significantly worse than PE scores for all participants in Experiment 6 regardless of which of the three exposure conditions they were in. The implication of this is that PE scores in the current study did not correlate with the other measures of spatial learning used because participants found the task too difficult (were unable to orient themselves) causing a floor effect. However, why this should be so in the current study but not in Experiment 6 is unclear.

Inferences concerning these findings must be made with caution since the two experimental environments, although similar, differed in a number of respects (see Method for details) and the locations from which participants were required to point to the unseen targets were also different within the two studies, indicating perhaps, that the findings could be attributable to procedural or environmental differences. However, that being said, the experimental environments were still far more similar than they were different, and the locations from which participants pointed were within the same quadrant of each environment in addition to being adjacent to the same virtual road. Other procedural differences between the studies must also be considered. In Experiment 6 exploration was guided, not goal directed and spatial learning was implicit, conversely in the current study exploration was free, goal oriented and spatial learning was explicit, all of which were hypothesised to facilitate spatial learning. However, a point worth considering is that the guided exploration of Experiment 6 took participants past the location subsequently used as the area from which they would point to unseen targets a guaranteed number of times; 5, 10 or 15 depending on which exposure condition they were in. Conversely, the fact that participants in the current study were free to explore the VE using a search strategy of their own choosing meant that there was no guarantee that they would pass the area from which they would subsequently point to unseen locations, although it would have been highly unlikely for them not to pass it at all. However, before we draw any conclusions from this difference between the studies, we have to acknowledge that passing a location during exploration does not automatically ensure that the location is noticed or encoded into a mental representation of the environment. As Darken and Peterson (2002) point out, it is impossible to attend to every stimulus and make use of it for spatial learning since much of it is irrelevant or at least of minimal importance.

Finally, regarding this particular finding we need to consider that participants in the current study spent less time exploring the VE than did participants in Experiment 6, who spent on average between 15 and 50 minutes navigating around it depending on which exposure condition they were in. Participants in the current study had only 10 minutes exploration time and it is possible that the extra exploration time experienced by participants in Experiment 6 facilitated their development of a mental representation of the VE and therefore their better performance on the pointing to unseen locations task. However, as mentioned above inferences from this particular finding must be made with extreme care particularly since other cross study comparisons were not possible due to differences between the measures. That being said, however, future studies could investigate the relative importance of time spent in an environment against other variables such as modes of exploration and learning.

SUMMARY

Despite the procedural changes implemented, the current study failed to demonstrate any advantage for active explorers over passive observers on any of the measures of spatial learning applied and in this regard replicated the findings of Experiment 6.

The findings indicating an advantage for real world drivers over non-drivers on two of the measures used to evaluate spatial learning, although far from being conclusive, may be indicative of competencies related to driving rather than an advantage in spatial learning per se and are worthy of further investigation.

This is particularly interesting, as many of the conclusions related to active / passive differences in spatial learning are based on studies that have indicated these differences between drivers and passengers in the real world.

The measures that correlated appear to support the idea of a parallel process of spatial learning as proposed by Montello (1998) rather than a serial process of spatial learning as proposed by Siegel and White (1975) and concur with the findings of Experiment 6 on this issue. However, the findings relating to PE scores indicate just how sensitive measures of spatial learning can be to procedural and or environmental differences between studies.

Chapter 10

FINAL DISCUSSION

The following discussion is subdivided into 4 sections. The first considers the findings relating specifically to active / passive differences in spatial learning. Section two considers findings related to working memory. Section three focuses on the findings related to the effectiveness of VEs as training media, the transfer of virtual experience to real space and the implications of the research findings for VE based training. Section four provides a summary of the key findings from this thesis and recommendations for future research.

Active-Passive differences in spatial learning

The studies presented here have utilised a range of methods and participant samples to investigate active / passive differences in spatial learning in virtual reality environments. They have all, however, been based on two main premises, one, that in the real world spatial learning is facilitated by activity (Piaget and Inhelder 1967; Appleyard 1970; Siegel and White 1975; Feldman and Acredolo 1979; Herman 1980; Hart and Berzok 1982) and two, that spatial learning in VEs is equivalent to spatial learning in the real world (Stanton, Wilson and Foreman 1996; Wilson, Foreman and Tlauka 1996; Ruddle, Payne and Jones 1997; McComas, Pivik and Laflamme 1998; Peruch & Gaunet 1998).

Following a logical progression from these two premises it was hypothesised that spatial learning in VEs should also be facilitated by activity. However, evidential support for this position from previous studies utilising VEs to investigate active / passive differences is equivocal, with many not demonstrating any advantage for active explorers (Peruch and Wilson 2002, Gaunet, Vidal, Kemeny and Berthoz 2001; Wilson 1999; Peruch & Gaunet; 1998) whilst a few have (Pugnetti, Mendozzi, Brooks, Attree, Barbieri, Alpini, Motta and Rose 1998; Peruch, Vercher and Gauthier 1995). It was reasoned, however that the methodological / design approaches used within the current investigation would be more effective at demonstrating active / passive differences in spatial learning than in previous investigations.

Since it has been consistently demonstrated that children in particular benefit from activity in the real world for spatial learning (Piaget and Inhelder 1967; Feldman and Acredolo 1979; Herman 1980; Herman, kolker & Shaw 1982; Benson and Uzgiris 1985) it was reasonable to assume that children would make ideal participants for a study investigating active / passive differences in VEs. This, and partially replicating a real world study, Herman (1980), that had reportedly demonstrated an advantage for active explorers, was the methodological coup (although this maybe overstated!) of the first two studies of this thesis that generated particularly interesting findings, as they demonstrated active / passive differences in spatial learning.

Surprisingly, despite the seemingly obvious advantages of doing so, to the author's knowledge no previous studies investigating active / passive differences in VEs have used children as participants. This seems strange particularly as most, if not all, of the previous real world experimental research in the area is based on work with children and has demonstrated that humans benefit most in terms of spatial learning, from active experience within environments during early childhood (Feldman and Acredolo 1979; Siegel, Herman, Allen and Kirasic 1979; Herman 1980; Herman, Kolker & Shaw 1982; Benson and Uzgiris 1985).

Previous studies using VEs in which children have participated have, however focussed on the developmental assessment of spatial abilities (Jansen-Osman and Wiedenbauer, 2004) or children's ability to transfer spatial information from virtual to real worlds (Foreman, Stirk, Mandelkow, Lehnung, Herzog and Leplow 2000; McCommas, Pivik and Laflamme 1998) or the remediation of spatial abilities in disabled children (Stanton, Wilson and Forman 1996; Wilson, Foreman and Tlauka 1996).

In Experiment 1 of the current investigations, with children, yoked passive participants demonstrated that they had formed more accurate cognitive maps of the experimental VE across trials than did active participants. One proposed explanation of this unexpected finding was that, in using the joystick to explore the VE, active participants were in effect performing a concurrent task to that of learning the spatial layout of the VE. This extra cognitive load was not experienced by passive participants giving them an advantage, whilst also negating the possible benefits that active participants might otherwise have gained. Note that, to the extent that a benefit of active control of spatial displacements is that the participant is provided with continuous feedback – perceptual changes that are contingent on their own decisions to move – this should be available in a VE just as in a real environment.

In Experiment 2 participants received prior training in the use of the joystick in order to reduce effort required of them to use it. It was reasoned that this approach should enable participants in the active condition to benefit from being active, as they would in real life, and that this would be demonstrated by their better spatial learning. In this instance the experimental hypothesis was supported. On the basis of their reconstruction abilities, active participants formed cognitive maps that were more accurate than those of their passive counterparts, across trials. From this finding, and that of Experiment 1 it was suggested that for children, spatial learning in VEs can be facilitated by activity, as it is in real environments. However, this can only occur if children are given the opportunity to familiarise themselves with the input device whilst using it to navigate virtual space, in order to reduce the competing cognitive demands of manipulating the input device (see Discussion of Experiment 2).

Therefore, Experiments 1 and 2 have demonstrated that spatial learning is sensitive to mode of exploration (active / passive) but also that another variable that must be considered is specific training, or VE acclimatisation. It must however, be conceded that the training effect revealed by the findings of Experiment 2 needs further investigation to verify its reliability and generalisabilty. Previous studies where participants have been extensively trained in input device usage and VE navigation have not demonstrated that training gives an advantage to active explorers over passive ones for spatial learning. Notably Wilson and Peruch (2002), who gave their participants 10 minutes training in a VE and Experiments 5 and 6 of this thesis in which participants had 5 minutes training. The amount of training required is likely to depend on the ease with which input devices can be used and the complexity of the VE-based task.

In Experiments 6 and 7 adult participants explored a complex VE in active / passive pairs. The experimental design and procedures were intended to replicate the driver / passenger scenario so often used to demonstrate active / passive differences in real world spatial learning, e.g., Appleyard (1970) and Hart and Berzok (1982). All the participants were given five minutes to familiarise themselves with the input device (a steering wheel and pedal arrangement), using it to drive around a virtual road track. Of the seven different measures of environment familiarity there was an active / passive difference on only one, in Experiment 6 passive participants remembered more landmarks than their active counterparts did. In this instance the finding was in line with the experimental hypothesis informed by the suggestion of Montello (1998) that remembering, 'what' rather than, 'where' is not necessarily spatial in nature and may not therefore be advantaged by activity. Consequently, it was reasoned that the concurrent task of navigating the VE would be detrimental for active participants' memory for landmarks despite prior training in use of the input device to locomote through virtual space. In contrast passive participants had little else to do other than view the objects encountered within the VE.

The other measures used in Experiment 6 were designed to measure aspects of learning that were more spatial in nature than merely memory for landmarks, and should therefore have been sensitive to the benefits of activity. In fact, none of these measures revealed any differences between the spatial learning of active / passive participants. Some possible procedural / design reasons were identified that may explain why it was that active participants did not perform as expected. These included the fact that participants in the active condition may have found the navigation task too attention-demanding since they had to follow road markings around the VE, which also meant that they could not explore freely. In addition, the task was low on motivation for participants, as it was not goal-directed; that is to say, participants were not asked to learn about the VE per se. These issues were addressed in the design of Experiment 7 in which active participants were given a search task and allowed to explore freely and asked to "get to know" the VE. However, once again the measures of spatial learning did not reveal any active / passive differences, despite participants having five minutes of pre-experimental training to familiarise themselves with the use of the input device.

Wilson (1999) suggested that the inconsistent findings in studies using VEs to investigate active / passive differences in spatial learning could be a result of the procedural differences between them. Wilson and Peruch

(2002) conducted a study designed to investigate the effects produced by different experimental procedures prompted by the fact that previously the study of Peruch et al (1995) had demonstrated an advantage for active explorers whereas the study of Wilson et al (1997), (which was based on that of Peruch et al [1995]), failed to do so. Wilson and Peruch (2002) included procedures from both of the previous studies such as yoked and non-yoked active / passive participants, within-participant and between-participant designs, and the manipulation of instructions telling participants what aspect of the VE they should be focusing on. They found that despite all of their procedural / design manipulations, in line with most of the previous research in the area, no advantage for active explorers was demonstrated. In their Experiment 1, however they found an advantage for passive participants on target location, orientation and a wayfinding task, although the latter was not consistent across the two laboratories, one in France and the other in England. In their Experiment 2 they found no active / passive differences at all and concluded that such differences were unreliable in studies using VEs.

As mentioned above, the current investigations have utilised a range of procedures, types of VE and measures of spatial learning. In Experiments 1 and 2, and 6 and 7, of this thesis, the active and passive participants were yoked, although passive participants in Experiments 2 and 7 viewed a pre-recorded video of an active participant rather than viewing an active participant's displacements in real time. The learning task was explicit in Experiments, 1, 2, 5 and 7 but hidden (incidental learning) in Experiments 3 and 6. In Experiments 1 and 2 a relatively simple VE was used, as in

Experiments 3, 4 and 5. However in Experiments 6 and 7 the experimental VE was complex. The measures used to gauge spatial learning included: landmark placement tasks (Experiments 1, 2, 4 and 5), pointing to unseen locations, map drawing and route finding (Experiments 6 and 7) and distance estimation (Experiment 3). It was considered that by using such a range of approaches to investigate active / passive differences the opportunity to reveal them would be maximised. However, with the exception of Experiment 1 where passive participants were surprisingly better than actives, and Experiment 2 where active participants were better than passives after extended training, and Experiment 7 where passives were, as predicted, better than actives at remembering landmarks, no active / passive differences were revealed. One possible interpretation of this pattern of results is that the detail of experimental design and procedures may not be as important for investigating active / passive differences in the current context as the age of participants.

As previously stated, most, if not all, real world experiments investigating active / passive differences in spatial learning have used children as participants and this was the motivation to do so here. Previous research, on the other hand, has also indicated that adults benefit from activity, and this is obviously one reason why researchers in the area (including the current author) have persevered with adult participants when children may be more suitable. However by and large, the cited research indicating the benefits of activity for adult spatial learning have been ecological / urban studies such as Appleyard (1970) and Ladd (1970), or theoretical / review papers such as Siegel and White (1975) and Hart and Berzok

(1982). It could be argued that the findings of this type of research are more difficult to interpret than perhaps those of experimental laboratory research (see also, Garling, Selart and Book, 1997).

Appleyard (1970) found that car drivers were better able to draw coherent city maps than were bus passengers and this has been often cited in subsequent papers as demonstrating the benefits of activity. However, is it activity per se, i.e., the physical act of driving and the mental act of making directional choices that enables drivers to draw better maps? Or is it because they get to experience more of a city, as they are free to move around it more or less as they please at what Beck and Wood (1976) describe as a 'geographic' scale? Bus passengers may also have a more limited, bus-route dominated, range than car drivers. Another advantage for drivers is that the act of driving itself forces them to attend more closely to where they are, where they are going and the routes they need to take. This means that environmental features such as street names, road signs, potential landmarks, distance and directional information carry more importance for the car driver than the casual passenger (Beck and Wood, 1976). The act of travelling by bus does not however preclude bus passengers from taking an interest in and learning the features and spatial layout of the environment through which they are travelling. However, unlike car drivers they are not *required* to do so and therefore it is likely that their attention is focussed elsewhere for much of their journey time, explaining perhaps why the maps of bus passengers are not as coherent as those of their car-driving counterparts!

Similarly, Hart and Berzok (1982) have said that car drivers learn more about the layout of a city than do car passengers and again this is cited as demonstrating the benefits of activity. However, if passengers attended to the environment during journeys to the same extent that drivers must, would their spatial learning be equivalent to or even greater than that of drivers since they are not performing the concurrent task of driving? Anecdotally speaking it is probably true to say that, unless they are assisting with navigation, in general car passengers do not particularly attend to routes, landmarks, etc and it is probably this lack of attention that limits their spatial knowledge when compared to car drivers who must attend.

In Experiments 6 and 7, in this thesis, the car-driver car-passenger scenario was recreated, by having passive participants either sit adjacent to participants driving around a virtual town centre or view video footage of them doing so. Obviously this arrangement meant that participants in both conditions had the opportunity to experience equivalent virtual journeys and that therefore any differences in spatial learning could not be due to one group having experienced more of the virtual town than the other, an explanation that might account for the differences found by Appleyard (1970) between car drivers and bus passengers.

Attention has also been identified as a possible confound in studies attempting to disentangle the hypothetical benefits of activity for spatial learning. Beck and Wood (1976) have suggested that drivers are more focussed on environmental features than are passengers, giving them an advantage. Conversely, Wilson (1999) has suggested that passive participants are able to compensate for their situation by focussing high levels of attention on the learning task, thus masking the benefits of activity in experimental studies. Therefore, in an attempt to control for this possible confounding effect, attention was manipulated across Experiments 6 and 7, in this thesis, by virtue of the instructions given to participants. In Experiment 6 participants in both conditions were not given any specific instruction to learn the layout of VE (incidental learning, low attention) conversely, in Experiment 7 participants were instructed to 'get to know' the VE (intentional learning, high attention).

Apart from the advantage for passive observers in Experiment 6, discussed above, no active / passive differences in spatial learning were revealed by Experiments 6 and 7 indicating that drivers in virtual space do not have an advantage over passengers when exposure to the environment is equivalent and instructions designed to regulate attention levels are the same for both groups. Interestingly, however, the findings of Experiment 7 demonstrated that participants who indicated that they were car drivers were more accurate than non-car drivers at indicating object positions on a map of the experimental VE regardless of which experimental condition they were in. They were also better than non-car drivers at route finding, if they had participated in the active condition. These findings were interpreted as possibly demonstrating particular competencies related to being a vehicle driver rather than demonstrating any advantage for activity per se. As suggested by Beck and Wood (1976), driving makes certain demands of drivers in terms of their environmental awareness, and therefore, it could be argued that if these demands are constantly met then specific and possibly transferable spatial skills related to environmental knowledge acquisition must develop. Beck and Wood (1976) also point out that since it is probable that car drivers are more familiar with map use than are passengers it is likely that they are better able to express there knowledge of environments via map based tasks than are passengers.

In conclusion, previous studies comparing drivers with passengers, such as those cited above, reportedly demonstrating the benefits of activity for the spatial knowledge of environments may not in fact be demonstrative of the benefits of activity itself but rather the consequential benefits of driving. That is to say, driving promotes a greater awareness of environmental features particularly those that are useful for wayfinding including landmarks, road signs, and directional decision points such as junctions. Added to this drivers are better able than passengers to engage in wide ranging and free exploration of environments increasing their familiarity with them and therefore enabling them to develop larger and more complete cognitive maps that may also be enhanced by their know-how of road map usage.

Other studies that have compared knowledge of environments in terms of modes of transport and found differences between those who travel by more active means than those who travel by more passive means may also be subject to the same interpretation as that given above. That is to say, motivation, attention and familiarity confound the benefits of activity and in ecological studies it is difficult to control for these confounds. However, as evidenced here, when these confounds are controlled for there appears to be little or no evidence to suggest that activity per se within VEs at least, is beneficial for adults' spatial learning.

For children, however, the picture appears to be very different and evidence presented here suggests that children's cognitive maps are sensitive, under the correct conditions, to mode of exploration in virtual environments, as it has been suggested they are in real ones. That is to say, the experimental findings here go some way to supporting the experimental findings of previous real space studies, such as those cited above, that have indicated activity benefits cognitive map formation in children.

An important difference between adults and children in terms of spatial abilities is that of cognitive maturity. It is likely that adults, with their greater experience of previously encountered environments and greater cognitive abilities, are better able than children to form mental maps of novel environments without having to explore them actively. On the other hand, it could be argued that children, who have less previous environment experience and who are not as well cognitively developed, are less able to conceptualise spatial relationships and are therefore more reliant on sensori-motor experiences such as active exploration to form accurate mental representations of environments.

Beck and Wood (1976) proposed that the more experienced traveller acquires generic spatial information concerning the cities s/he has visited and is able to use this general knowledge to decipher the layout of a novel city. From a developmental point of view, Piaget (1968) proposed that as the spatial abilities of children develop they become less reliant on sensori-motor schemata and can construct spatial memories with much less stimulus support. This is exemplified by the study of Kosslyn, Pick and Fariello (1974) who found that, when compared to adults, children overestimated the distances between objects even when they could be observed through a transparent barrier. Conversely, adults' overestimates occurred only when the barrier was opaque. They concluded that whilst adults have the ability to make accurate distance judgements from visual information, children require information based on the physical effort to move from one location to another. This position is supported by the findings of previous research such as that of Herman, Kolker and Shaw (1982), Herman (1980), Siegel, and Herman, Allen and Kirasic (1979) all of whom found that as children get older they rely less on activity to form cognitive maps. Evidence to support the idea that spatial abilities improve with maturation is also provided by Experiment 1 in the current thesis, in which it was observed that placement error scores improved as a function of age across both trials and conditions. It may be that younger children are more dependent on activity for spatial learning because they form representations from a more egocentric perspective than older children and adults.

If, as evidence suggests, as humans mature to adulthood their dependency on activity per se to form accurate mental representations of environment spatial layouts diminishes, what impact does this have on the test environments used for research looking at active / passive differences in spatial learning? Previous research looking at the effects of activity on spatial learning reveals that most if not all of the experimental research with children uses environments described as "large scale" but which are, relatively speaking, small in size, such as rooms, scale-models and even sand-pits. For Weatherford (1982) these spaces are what he terms small-scale navigable, since they are large enough to permit movement within them but can, in their entirety from a single vantage-point. Conversely, as mentioned above, the studies most commonly cited as looking at adults' spatial learning and activity have tended, by and large, not to be experiments and have tended to look at spatial knowledge of truly large-scale and complex environments such as cities or buildings.

From the pattern of research described above it could be argued that in real world studies, small experimental environments have proved to be adequate to differentiate active from passive child explorers but they have not been the environments of choice for experimenters investigating active / passive differences in adult spatial learning. Herman, Kolker & Shaw (1982), who found no active / passive differences in third graders spatial learning of a small experimental environment but an advantage for active kindergarteners, suggested that for the older children, when 'task-demands' are low, the effects of activity may have negligible or no have no effect on spatial learning. This finding must be taken to support the notion that testing adults on their knowledge of small environment spatial layouts might not be sufficiently challenging to differentiate active explorers from passive ones. Both active and passive participants may perform equally well in small simple environments, so that it might only be possible for active participants to demonstrate an advantage in spatial learning in large and complex environments. This might explain why much of the research in the area is based on the findings of urban field studies such as Appleyard (1970), Ladd (1970) and Lynch (1960).

Virtual environments have been viewed as ideal for studying human spatial learning not least because they can be customised to the researcher's requirements. VEs can be small and relatively simple, like the real world experimental environments used with children, or large and complex renditions of building interiors or the urban and rural environments routinely inhabited and navigated by human beings. Theoretically, this means that VE technology offers researchers the opportunity to investigate adult spatial learning in large complex and naturalistic environments with the same experimental control as that enjoyed by researchers investigating children's spatial learning in small experimental environments and should therefore enable the development of a clearer picture of how environment scale and complexity affect spatial learning.

Studies using VEs have, however, not demonstrated any clear results to indicate that scale and complexity have any consistent effect relating to the active / passive dichotomy. For instance in Experiment 6, in this thesis, both active and passive participants performed to an equivalent, very high level of accuracy, when compared to guessing controls, on a task requiring them to indicate the positions of objects encountered within a room-sized VE on a paper floor plan of the VE. This finding would appear to support the low-task-demand hypothesis and suggests that both groups reached a ceiling effect for the task. Conversely, however, in Experiment 4, active and passive participants produced the same degree of distance estimation after travelling along a simple virtual corridor with three objects located at various positions along its length. After exploration, participants were asked to indicate the positions of the objects encountered within the VE whilst walking along the equivalent real corridor. Despite apparent low task demands participants in all conditions demonstrated a substantial distance underestimation effect. However, distance underestimation has been show to be an extremely robust effect in VEs (Hayashibe, 2002; Henry & Furness, 1993; Kline, 2003; Witmer & Sadowski, 1998) and as demonstrated here equally affects both active and passive explorers of simple VEs even when active explorers are using input devices offering considerable proprioceptive and kinaesthetic feedback. Experiments 6 and 7, in this thesis, utilised a large and complex environment designed to replicate a small town centre comprising many buildings of various types, open spaces with trees and a complicated road system. Such an environment, it was thought, would be highly suited to demonstrating active / passive differences in spatial learning as demonstrated by the urban studies of Appleyard (1970), Ladd

(1970) and Lynch (1960), however, both groups again performed equivalently across a range of measures.

Therefore, if activity is advantageous for adults' spatial learning, in VEs at least, manipulation of environmental scale and complexity does not help to demonstrate this. The spatial learning of active and passive participants was equivalent in experiments using both small simple environments and those using large complex environments. It could be argued that this is a further demonstration that activity is not in fact advantageous for adults and that given equal access to an environment, passive viewers are as able to acquire spatial information as motorically active explorers, even when attention is mediated by experimental instructions. On the other hand it could be argued that virtual environments do not replicate real environments to the extent that active / passive differences can be demonstrated. However, it has been shown here that active / passive differences are demonstrable in experiments using VEs with children, who appear more reliant on activity than adults.

The findings with child participants support those of previous real world experimental studies that have consistently demonstrated that children's spatial representations benefit from activity. That this is also consistently the case in VEs needs to be further researched. Also, despite all the similarities, virtual space is qualitatively different from real space. and whilst we have to a certain extent discarded, as demonstrating the beneficial effects of activity per se, the ecological studies discussed above, we acknowledge that properly controlled real world experiments are needed to further investigate the impact of activity on adult spatial learning in the real world. The results of such studies could then be constructively used to inform further research using virtual environments as has been the case within the current thesis with previous real world experiments looking at children's spatial abilities. Added to which, in addition to furthering our understanding of adult spatial learning such an approach might also enable further understanding of the differences between the spatial properties of virtual and real space in terms of their utility for human spatial learning.

Working Memory

The hypothesis, generated by the findings of Experiment 1, that passive participants were better than actives at reconstructing the real model after exploration of its virtual equivalent because the extra cognitive load experienced by active participants was explored in a number of ways. Experiments 2 and 3 both employed approaches designed to reduce the cognitive load experienced by active participants whilst Experiment 4 employed the concurrent task methodology enabling the manipulation of cognitive loading during a spatial learning task.

In Experiment 2 participants were given practice with the input device prior to exploration of the experimental VE. It was hypothesised that extended practice would reduce the mental effort required of participants using the input device to navigate the VE thereby freeing processing capacity for the retention of spatial information. As participants in

Experiments 1 and 2 were children this was seen as being of particular importance due to the known developmental constraints of working memory (Pascuell-Leone, 1970; Case, Kurland and Goldberg, 1982; Cowan, 1997 and others). In this case the experimental hypothesis was supported and active participants demonstrated superior spatial learning to their passive counterparts. It was suggested that the extra training reduced the cognitive load experienced by active participants enabling them to benefit from actively moving through the VE in the same way as they did walking through a real environment as in the study by Herman (1980).

The findings of Experiment 2, then, demonstrate that training can make input device use, within the context of VE exploration, less demanding and presumably more natural for active participants, enabling them to focus more on learning the spatial layout of a given VE. Therefore, if active participants are able to use an input device that enables them to mimic a natural movement such as walking to locomote through a VE then active participants should learn more about that VE than passive ones. In Experiment 3 this statement was tested by having active participants locomote down a simple corridor VE using a gait driven input device. That is, active participants stood on the device and performed a walking action that 'moved' them along the virtual corridor. The experimental hypothesis was that virtual movement controlled by a natural action such as walking would require minimal cognitive effort and would therefore allow active participants to demonstrate superior spatial learning, in terms of a distance estimation task, to that of their passive counterparts.

However, in this instance the experimental hypothesis was not supported and active and passive participants performed to a statistically equivalent level. Assuming that the original hypothesis was correct, there are a number of possible explanations for this result.

Firstly, as discussed above, the distance underestimation effect is a highly robust one in VEs (Hayashibe, 2002; Henry & Furness, 1993; Kline, 2003; Witmer & Sadowski, 1998) probably due to the foreshortening effect of viewing spatial cues related to depth on flat 2-D screens. Think of how short a tennis court or cricket pitch looks when viewed from end to end on television. When one considers that vision is the predominant sense for spatial learning, particularly in VEs, then it might be of no great surprise that the benefits of activity are not strong enough to counteract the foreshortening that leads to distance underestimation.

Secondly, as established above, adults do not depend on activity to the same extent as children to form spatial representations, particularly in simple environments. Therefore, since the participants were adults, it could be argued that those in the passive condition were not at all disadvantaged when compared to those in the active condition and were able to form equivalent spatial representations, with both groups being equally prone to underestimating distances.

A third contributory factor to the findings could be that of the input device. Whilst the step-device enabled active participants to move through the environment using a natural walking gait it did not allow for changes in direction. This meant that active participants could only move forward in a straight line and had no opportunity to make meaningful directional choices that could be reinforced by the reafferent feedback of motor activity. Obviously such constraints impact on the type of VE and measures of spatial learning that can be used, in this case a corridor and distance estimates respectively. Further studies containing a walking device allowing changes in direction of movement, would indicate how important is mode of input for spatial learning in a more complex virtual spatial environment. Had active participants been able to initiate changes of direction in a more complex VE thereby allowing us to administer a range of measures such as wayfinding, orientation and map drawing, active / passive differences may have emerged. Indeed findings indicating that input devices providing proprioceptive feedback and allowing a fuller range of movements lead to better spatial knowledge acquisition in terms of orientation were reported by Bakker, Werkohoven and Passenier (1999) and Chance, Gaunet, Beall and Loomis (1998). Conversely, however, (Kline, 2000) demonstrated that proprioceptive feedback during VE exploration enhanced subjective feelings of movement but did not reduce distance underestimates. Therefore, whilst intuitively at least, interaction with a VE via an input device designed to work with the explorer's natural body movements would appear to offer greater potential for spatial learning the current support for this idea is equivocal.

In Experiment 4 the problem of cognitive load was approached not by attempting to alleviate it but rather by implementing the concurrent task methodology commonly used for gauging resource demands on working memory. If a concurrent task disrupts performance on a main task then it is said to be competing for the same limited resource mechanism as the main task, with both tasks combined exceeding the cognitive resources available. However, if performance is not disrupted it might be that that the combined task demands do not exceed the limited resources available or that they are utilising different mechanisms of working memory - visual and phonological for instance.

The findings of Experiment 4 were that participants who performed a concurrent complex spatial motor task (card sorting or keyboard shadowing) demonstrated significantly impaired spatial learning in terms of object location when compared to controls who performed no concurrent task, whilst viewing a video of displacements around a simple VE. Participants who performed low demand spatial motor or verbal memory secondary tasks were not statistically worse than controls.

The findings of Experiment 4 support the idea of a limited resource visuo-spatial component of working memory, the capacity of which was exceeded by the concurrent tasks of learning the layout of the experimental VE whilst performing one of the complex spatial motor tasks. Therefore by implication, these findings also go some way to supporting the assertion made here that active participants of spatial learning research using VEs are disadvantaged by the concurrent task of using an unfamiliar input device to navigate unfamiliar space whilst trying to learn the layout of that space. The two complex spatial motor tasks used in Experiment 4 were assumed to approximate the cognitive load of using an unfamiliar input device. As demonstrated by the findings of Experiment 1, this type of loading appears to have a detrimental effect on spatial knowledge acquisition in children. As discussed above, the majority of studies with adults have not indicated any advantage for active explorers of VEs in terms of spatial learning, perhaps reflecting an impediment due to using an unfamiliar input device outweighing any advantage conferred by active exploration. However, adult active explorers, within the context of the current thesis and in other studies, have been given the opportunity to familiarise themselves with input devices, presumably reducing the cognitive effort required to use them and yet they have still not consistently demonstrated an advantage in spatial learning over their passive counterparts.

Therefore we might conclude that for adults the imposition of using an unfamiliar input device to actively explore virtual space is insufficient to disrupt their spatial learning to the extent that it is worse than that of passive observers. On the other hand, however, even with input device training adult active explorers appear to be no more advantaged than passive observers when it comes to learning the spatial properties of virtual environments.

The finding of Experiment 4, that a complex concurrent spatial motor task disrupts adult spatial learning might be explained in one of two ways. It might simply be that the complex concurrent tasks used in Experiment 3 are more cognitively effortful to perform than the task of using an unfamiliar input device. Equivalence cannot be assumed. However, a more sophisticated explanation is that input device usage for navigation is congruent with a primary spatial learning task whilst the concurrent tasks of Experiment 3 were not congruent with the primary task. This could be interpreted as indicating that task *congruence* is negatively correlated with resource demands. In other words, as secondary task congruence to a primary task increases resource demands decrease. On the other hand it might be that the threshold at which a congruent secondary task disrupts a primary task is higher than that of an incongruent secondary task. That is, a congruent secondary task can be more resource demanding before it disrupts performance of the primary task. These possibilities need to be further researched.

For children however, the effect of a concurrent cognitive load appears to have a more significant affect on their ability to form accurate spatial representations than it does for adults. In Experiment 1 active participants experienced a high cognitive load due to the novelty of using a computer joystick to explore virtual space and were significantly worse than their passive counterparts on an object placement task. In Experiment 2 the cognitive loading experienced by active participants was reduced via prior training, resulting in superior spatial learning. Therefore, it could be argued that the additional cognitive load experienced by children given no prior training in the use of input devices is equivalent to the cognitive load experienced by participants of

Experiment 4 who performed complex concurrent spatial motor tasks and whose spatial learning was disrupted. On the other hand children who have had input device training could be said to experience cognitive loading equivalent to that of participants in Experiment 4 who performed a simple spatial motor task and whose spatial learning was no worse than the controls who did not perform any concurrent task. These findings would appear to indicate support for the hypothesis that children are more sensitive to both the detrimental effects of concurrent cognitive loading and the benefits of active exploration than are adults. In turn, this supports the case presented above, suggesting that children make more suitable participants for research looking at active / passive differences in spatial learning than do adults.

In summary then, the idea that cognitive loading is a significant factor in findings indicating no advantage for active explorers of VEs over passive observers, in terms of spatial learning, is difficult to reconcile with the evidence currently available. Whilst it has been demonstrated here that a complex concurrent task unrelated to input device usage and VE exploration does disrupt a primary spatial learning task there is no evidence to suggest that the concurrent task of input device usage, would disrupt spatial learning to the same extent. Moreover, experiments within the current thesis and elsewhere have demonstrated that procedures designed to reduce the cognitive load of using an input device, such as training and type of input device, do not enable active explorers to demonstrate any advantage over passive observers as might be expected. This may be taken to further illustrate that for participants of a certain cognitive developmental level any disruption or advantage conferred by input device usage is minimal. For children, however, the situation may be very different as evidence suggests that they are sensitive to both the possible disruptive and beneficial effects of input device usage for VE navigation in terms of spatial leaning. Children at a certain cognitive level using an unfamiliar input device to explore virtual space can experience disruption of a spatial learning task due to the additional cognitive loading. However, children who have received training with such a device, reducing the cognitive effort required to use it, are able to demonstrate the benefits of activity in their spatial learning of experimental virtual spaces as they can in experimental real spaces.

Spatial Learning and its Transfer to Real Space

Whilst active / passive differences in VEs have not been reliably demonstrated it is generally accepted that VEs convey good spatial information that, is at least functionally, equivalent to that available from real environments (Wilson, 1999; Peruch and Gaunet, 1998 and others). It is also generally accepted that the spatial knowledge acquired from VEs is transferable to real space (Ruddle, Payne and Jones, 1997; McComas, Pivik and Laflamme, 1998). Psychological studies that have demonstrated the effectiveness of VEs as good media for imparting spatial information have generally trained participants in the virtual equivalents of the real environments in which their spatial learning is subsequently tested. These studies, for instance Ruddle, Payne and Jones (1997) and McComas, Pivick and Laflamme (1998) among others, have generally found that people trained in VEs are able to demonstrate spatial learning equivalent to that of people trained within or with experience of the equivalent real environments.

The present studies have also demonstrated that spatial learning in VEs is effective and transferable and, for adults at least, not necessarily dependant on activity. This was specifically demonstrated by the findings of Experiment 5 in which active and passive participants demonstrated their spatial knowledge of a simple VE by indicating object relational positions encountered within the VE on a paper floor plan of the VE. Both groups performed to an equivalently high level of accuracy and were significantly better than a control group who did not experience the VE and had to guess the object positions. This study clearly demonstrates that spatial learning *has* taken place and that spatial learning and survey type knowledge transfers from virtual to real space (McComas et al, 1998; Ruddle et al, 1997; Stanton et al, 1996; and Wilson et al, 1996). It also demonstrates that active and passive participants are equally good at picking up spatial information from VEs, rather than being equally bad.

Experiments 1 and 2 in which participants demonstrated their spatial knowledge of a VE using a real space model on which to place objects encountered within the VE also indicate that good spatial information, that is transferable, is available from VEs. They also show that the age and practice effects evident in spatial knowledge acquisition of real environments by children is replicated in virtual environments, adding to the body of knowledge that indicates that the spatial properties found in real and virtual environments share many similarities (Peruch and Gaunet, 1998; Wilson et al, 1997).

More supportive data for this position were revealed by Experiment 6 in which participants experienced a complex VE under one of three length of exposure conditions (in addition to being in either the active or passive condition). The study revealed that spatial learning, measured along several dimensions, increased as a function of exposure duration, or in other words familiarity, in the same way as one might expect to happen as experience of a real environment increases. However, these findings appear to be more supportive of Montello's (1998), parallel processing model of spatial knowledge acquisition in which he proposes that metric configurational knowledge is acquired along with landmark and route knowledge at initial exposure to a novel environment and develops quantitatively as familiarity increases. This is opposed to the predominant model proposed by Siegel and White (1975) in which it is suggested that spatial learning follows a serial hierarchy where knowledge of landmarks is acquired first, followed by knowledge of routes between landmarks before, finally, configurational environmental knowledge develops.

Clawson, Miller and Sebrechts (1998) assessed transfer of route learning from virtual to real space based on measures of correct turns, hesitations and distance estimates and found that VE training was comparable to both map and real world training. However, they also found that VE trained participants showed substantial specificity not demonstrated by participants in the other learning conditions. When testing was in the opposite direction to that in which the VE was originally experienced they were worse than participants trained in the real building on the original measures and also worse than map trained participants on distance estimates. However, a subsequent study by Sebrechts, Mullin, Clawson and Knott (1999) demonstrated that VE-trained participants allowed to explore freely during training rather than being required to follow a one-way-route around a VE were significantly better than map trained participants at finding the most economical route around the equivalent real environment.

Whilst spatial learning transfer is clearly demonstrable, there are design issues that must be considered as illustrated by Sebrechts et al's (1999) finding that spatial learning is more flexible after free exploration rather than guided exploration. However, as demonstrated by the findings of Experiments 6 and 7 of this study, free exploration does not guarantee that explorers of VEs will experience enough of an environment during a limited time to make accurate pointing-to-unseen-location judgements from any given location. On the other hand, guided exploration can ensure that explorers visit all areas of a VE that are salient to the intended learning. This is just one example of a design issue that must be considered when using VEs for training purposes. Therefore when designing a VE-based spatial learning study or training programme there might be a trade off between giving explorers an experience leading to an orientation-free mental representation (free exploration) and ensuring they experience all of the environment required for subsequent testing or training (guided exploration). This kind of consideration clearly illustrates the multifaceted nature of spatial learning and the multitude of variables that can effect human mental maps. With regard to exploring active / passive differences in VEs, it is probable that different measures will result in different outcomes because they reflect different aspects of spatial cognition or because they differ in their sensitivity (Wilson and Peruch, 2002).

A controversial issue that needs to be considered when looking at training and transfer of spatial knowledge is that of gender differences in spatial performance. It has been frequently reported that males typically perform better than females on spatial tasks (Linn and Petersen, 1985; Voyer et al, 1995). Astur, Ortiz and Sutherland (1999) suggested that gender differences are particularly likely to appear in virtual tasks. If VE-based spatial training does increase the gender bias in performance, then where the use of VEs for training is to facilitate transfer of spatial knowledge to real space, women might disadvantaged. However, other studies, such as Waller (2000) have shown that gender is a relatively minor factor in determining performance on spatial tasks, particularly when the effects of computer game familiarity is factored out. No gender differences where observed on any performance measures used for this study, except distance underestimation. Further research is required to attempt to establish whether VE-based training increases or alleviates existing gender biases in spatial performance.

Another issue related to the transfer of spatial learning from VEs to the real world is that of naturalism or realism. When undertaking VE-based training for tasks that will subsequently be performed in real space, it may be advantageous to use input devices providing a natural form of interaction. That is, spatial learning that is transferred from virtual to real environments may be facilitated by locomotion devices that reproduce a realistic or natural mode of travel. Such devices offer several advantages since users can easily perform tasks based on principles and movement patterns with which they are familiar from daily life. However, as demonstrated by the findings of Experiment 3, if such devices are poorly designed or used in an inappropriate context they may offer no advantage over standard input devices. This issue needs further investigation for empirical research purposes, although, as outlined below, the real world applications of VEs for industrial and training purposes already demonstrate that good transfer of spatial learning transfer is possible without too much consideration of the naturalism / realism factor.

Gender differences in spatial learning

Gender differences, in favour of males, have been shown to occur when tasks involve the mental rotation of objects (Linn and Peterson, 1990; Voyer, Voyer and Bryden, 1995) and when gathering spatial knowledge from VE exploration (Astur et al,1998), however the present data are inconclusive. A significant advantage for males was demonstrated in Experiment 3, which was surprising and difficult to account for as the experimental task did not involve any mental rotation and, to this point the underestimation effect found in Experiment 3 and in previous research

(Hayashibe, 2002; Henry and Furness, 1993; Kline, 2000; Ruddle, Payne and Jones, 1997; Witmer and Sadowski, 1998) has not been shown to differentially affect genders. In Experiment 2 males were arithmetically and almost significantly better than females, however, since Experiment 2 employed the same VE and spatial task as Experiment 1, in which there was absolutely no indication of any gender difference, this again is difficult to reconcile. After testing large samples of males and females on a variety of spatial tests, including VE-based tests, Waller (2000) concluded that the contribution of gender per se to VE spatial knowledge acquisition is not substantial, especially when the effect of differential computer usage is factored out. This would appear to be supported by the current findings since no consistent or reliable gender effect has been shown, contrary to the conclusion of Astur, Ortiz and Sutherland's (1998) that gender differences in spatial performance emerge particularly clearly when participants are tested in VEs. However, there still remains the possibility that, as a result of using different spatial strategies, males and females make differential use of VE-based information and this is worthy of continuing investigation.

Key findings and recommendations for future research

The series of experiments undertaken here show that VEs provide a substantial level of spatial information acquisition that is at least functionally equivalent to that offered by real environments, in line with many previous findings (Stanton, Wilson and Foreman, 1996; Wilson, Foreman, Tlauka, 1997; Ruddle, Payne and Jones,1997; McComas, Pivik and Laflamme, 1998). In simple environments people are able to learn the locations of objects to a high level of accuracy whilst in more complex environments they can learn routes and form mental representations allowing them to point to unseen locations within those environments. In addition, as observed in real environments, people's mental representations of VEs also become more accurate with familiarity over time. The equivalence of virtual and real spatial information is further illustrated by the transferability of spatial competencies from virtual to real space as demonstrated here and by studies such as Foreman, Stanton, Wilson, Duffy and Parnell (2005), Foreman, Stanton, Wilson, and Duffy (2003) McComas, Pivik and Laflamme (1998) and Ruddle, Payne and Jones (1997).

However, despite all of the demonstrable similarities between VEs and real spaces in terms of the spatial information they afford, the current investigation has not demonstrated that activity is beneficial for adult's spatial learning in VEs as previous studies have indicated it is in real space. Indeed, the current investigation adds to the body of previous studies using VEs to investigate active / passive differences in spatial learning by yielding findings indicating that for adults, when everything else is equal i.e., exposure, attention and motivation, participants who experience a VE actively have no advantage in spatial learning over those who experience it passively.

The finding that adult spatial learning is not subject to the same benefits of activity in virtual space as it is, supposedly, in real space may be attributable to one of two possibilities. Firstly, as discussed to some extent above, the basic premise that adult spatial learning benefits from activity per se may be faulty. That is to say the previous non-experimental studies on which much of the subsequent research in this area has been based demonstrates the benefits of environment familiarity stemming from accessibility and greater range as a consequence of more autonomous forms of transport such as driving when compared to forms of public transport and walking (Appleyard, 1970; Ladd, 1970; Hart and Berzok, 1982). Added to this, driving requires that more attention is paid to environmental cues (Beck and Wood, 1976) and it is likely that for adults attention is a crucial factor in spatial learning (Wilson and Peruch, 2002).

A second possible explanation is that despite all the similarities, virtual and real spaces are not truly equivalent and might not therefore offer active explorers the same potential advantages as those they might experience in real space. For instance, VEs, both desk-top and immersive, provide a limited field of view when compared to real space, offering no peripheral visual stimulation, and the interaction via standard input devices such as keyboard, mouse and joystick lack the kinaesthetic and vestibular feedback experienced by active explorers of real space. In addition to which, even when exploration is controlled via more sophisticated devices that provide more feedback than the standard control over displacements and level of feedback is still impoverished when compared to real world physical exploration.

However, whilst VE technology cannot currently provide an experience that authentically replicates real world experience, evidence from the present studies indicates that for children activity within VEs can facilitate spatial learning in a way that is comparable to real world studies. On this basis, therefore, activity for adults does not appear to afford any advantage in terms of the formation of accurate spatial representations. Therefore, since previous real world data relating to activity and adult spatial learning are equivocal, new real world experimental studies need to be devised in order to examine the influence (or lack of influence) of activity on adult spatial learning and thereby inform future virtual studies in the area.

Future real world studies with adults need to be experimental in design in order to effectively control for confounding variables, specifically familiarity and attention, which the present review suggests may account for previous findings that have been cited as indicating the benefits of activity. For instance, it has been assumed that car drivers' superior environmental spatial knowledge is a direct consequence of their active engagement with the environment, as compared to, for example bus passengers (Hart and Berzok, 1982; Appleyard, 1970). However, car drivers have the opportunity to experience more of urban layouts because they can go where they please and are not restricted to bus routes and are required to attend to environmental cues to a greater extent than bus passengers. However, a car passenger who is given an opportunity to experience as much of an environment as their driver and who is required to attend to the environment to the same extent as the driver (Beck and

Wood, 1976) may learn as much (or perhaps more) about that environment. If it is demonstrated that activity is not necessary for good adult spatial learning, then this has implications for VE- based spatial training. For example, new employees who experience a virtual rendition of their new work place (e.g. an oil platform) prior to commencing work may learn just as much about the layout from viewing a pre-programmed tour of their new work environment, as they would do from actively exploring it themselves. This would mean that familiarisation sessions could occur on a group rather than an individual basis with obvious cost saving implications.

A further avenue of investigation with adults would be to follow up the findings of Experiment 4, in which it was shown that concurrent tasks with a visual-spatial component interfere with spatial learning of a VE layout. Introducing another main task that has no spatial component, e.g. pure object memory in the same virtual environment could refine this study. If under these conditions the spatial interference effects disappear, it is likely that a spatial interference is relevant and hence VSSP contributes to spatial learning. Additionally it would be interesting to examine spatial learning in an active condition for the same environment because, if the above assertions relating to the interference effect of input device usage are accurate, performance should be at the equivalent level to that of the present spatial interference group.

The findings here indicate that the situation for children is different from that of adults, insofar as activity has been demonstrated to have an effect on their spatial learning of VEs. This supports previous real-world experimental data that activity is beneficial for children and it is surprising that a review of the literature has yielded no previous studies using VE's to specifically explore active / passive differences in children's spatial learning. This is particularly surprising considering that some studies do exist that use VR as a spatial training medium for children with spatial deficits arising from locomotor restrictions. For example, Stanton, Foreman and Wilson (1998) conducted a study that suggests that virtual experience can compensate for a lack of independent movement in space and can encourage spatial thinking in children with movement disabilities.

However the situation with children is complicated and needs further investigation. Whilst children's cognitive immaturity means that activity is a beneficial factor in supporting their spatial learning, ironically it also means that the concurrent task of using an input device to actively explore VE may be deleterious to their spatial learning of VEs. That is to say, they cannot focus all their attentional resources on learning the layout of the VE when having to use an unfamiliar input device to actively explore it. Two of the experiments reported here indicate both possible benefits and deficits of activity for children's spatial learning. In Experiment 1 passive children performed better than the active participants, whilst in Experiment 2, after greater familiarisation time with the input device, active children performed better than did the passives. These findings suggest several possible future avenues for investigation using VEs. Firstly, the issue of the amount of training required by child users of VEs in order for them to experience the benefit of active exploration needs to be addressed, including consideration of co-variables such as age differences, input device type differences and VE type differences (scale, complexity). Secondly, previous real world studies have shown age-related differences in spatial learning and these have been supported to some extent by the findings of this investigation, but require further study. Using VEs affords the opportunity to investigate developmental differences in spatial learning, particularly those related to the benefits of activity. For instance, two interesting questions to explore are "At what age do the benefits of activity cease to be significant for the formation of mental maps?" and "At what age are the benefits of activity maximum in facilitating spatial learning?" Answers to these questions would have practical value for VE spatial training for children with spatial deficits. Thirdly, as discussed above and as demonstrated by the present experiments, spatial learning successfully transfers from virtual to real space, and as demonstrated in Experiments 1 and 2, the age and practice effects found in real world spatial learning can be replicated for virtual space spatial learning. However, the key finding that activity benefits children's VE spatial learning must be considered as tentative, until further empirical research is undertaken to substantiate this premise.

In conclusion to this study, it is clearly valuable to investigate the benefits of activity for spatial learning using experimental methodologies and VEs, as this approach provides robust methodologies to explore the fundamental components of this complex process. However, it is important to recognise when adopting this approach that in natural settings (as opposed to the experimental ones) motor activity serves a multitude of cognitive and social purposes other than spatial learning. It is therefore unlikely that the experimental context will ever provide the motivations and nuances that real goal-driven activity in real space does, and the influence of these elements on adult spatial learning cannot be underestimated. This might explain why the literature regarding activity and adult spatial learning is predominantly focused around naturalistic studies looking at peoples' representations of their local environments. On the other hand it appears that the effects of activity per se are more easily disentangled from other variables when investigating children's' spatial learning and it is experimental work with children that might provide the most profitable route for further investigation of activity effects on spatial learning.

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Appendix 1

Forced choice questionnaire requiring participants to indicate the direction of a target location from a described present location

Please answer all the questions below by circling the appropriate response. Try as hard as you can to answer correctly but guess if you have to.

1. At the junction with the blue statue on your right in which direction is the baby sitter?

   Left. Right. Straight-ahead.

2. At the junction with the car park on your right in which direction is the roundabout?

   Left. Right. Straight-ahead.

3. At the junction just after the school on your left in which direction is work?

   Left. Right. Straight-ahead.

4. At the roundabout with the gold statue directly to your right in which direction is work?

   Left. Right. Straight-ahead.

5. At the junction with the blue statue on the opposite left hand corner, in which direction is home?

   Left. Right. Straight-ahead.

6. At the junction just after the Kentucky Fried Chicken restaurant on your left in which direction is the college?

   Left. Right. Straight-ahead.

7. At the junction with the school on the opposite right-hand corner in which direction is the Baby sitter?

   Left. Right. Straight-ahead.

8. At the junction after the babysitters with the car-park on your left, in which direction is the school?

   Left. Right. Straight-ahead.

9. You approach the roundabout over the zebra crossing with the post-box to your right. In which direction is the college?

   Left. Right. Straight-ahead.

10. You approach a junction past a telephone box and a single tree to your left, in which direction is Tesco

    Left. Right. Straight-ahead.